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SENSITIVITY OF THE EYE TO THE SATURATION OF COLORS

BY DOUGLAS McGREGOR

Harvard University

Psychologists have for years been seeking a satisfactory quantitative measure of the sensitivity of the eye to color. Sensitivity to brightness can be adequately expressed in terms of the absolute and differential thresholds; but most of the suggested measures of color sensitivity have been indirect and not satisfactory. Measurement of the number of perceptibly different hues in a given spectral range is interesting, but unsatisfactory as a practical index of sensitivity or as a fruitful source of information concerning the nature of the retinal mechanism. The same thing can be said of most of the other attempts to solve the problem. Color-mixture equations constitute an exception, but even they have not led to a tenable physiological theory.

It is surprising, in view of the importance of the problem, that there have been so few attempts at its solution by a direct frontal attack. An adequate technique has never been devised for the measurement of the threshold for saturation. Saturation is amount of hue. It follows, therefore, that measurement of the absolute threshold for saturation (the least amount of hue perceptibly different from a 'white' of the same brightness) is direct measurement of sensitivity to color.

Geissler (4) measured the least perceptible *de*saturation of several hues at one level of brightness. He used 10 subjects, one of whom was color-blind. He found, as might be expected, that the threshold varied markedly from eye to eye, and that the color-blind subject required that much more white be added to a given hue in order that he might perceive a difference between the maximally saturated hue and the mixture, than was the case with the other subjects.

Geissler used pigment papers, and it is not at all certain that he succeeded in avoiding errors due to differences in brightness. He stated that the hues and the grays were equated in brightness by flicker photometry, but it appears that he made one set of equations which were then presumed to hold for all his subjects. It is well known today that a brightness equation between a hue and a gray for one eye cannot be presumed to be valid for another eye. The present author made a preliminary attempt to use pigment papers, but he was forced to abandon them because of the practical difficulties in obtaining brightness matches. Accurate measurement of the threshold for saturation, particularly with color-blind subjects, is completely dependent upon the validity of the brightness match between the gray and the hue. At the threshold even a subject with acute color vision usually cannot tell whether the observed difference is one of saturation, of hue or of brightness. There is only one way to be sure that the difference is one of saturation, and that is to provide an experimental technique where the only variation in the system is a variation in saturation. This requirement necessitates brightness equations for each subject prior to each set of judgments of saturation. Since Geissler did not state that this precaution was observed, it is probable that he did not recognize its importance. Thus the validity of his data is open to question.

There is only one other reported experiment in which the absolute threshold for saturation was measured. Priest and Brickwedde (12) measured what they called the 'least perceptible colorimetric purity' at 10 mμ intervals throughout the spectrum. They used two subjects. Their technique seems to have been adequate (the only published report of

their work is a brief abstract) and their data are used in most general discussions of color vision. Their interest was primarily in the question of the relative saturations of the different spectral regions. They measured the threshold at only one level of brightness (between 3 and 4 millilamberts). In addition, they used a 4° field, a size which means that both rods and cones were involved. It would seem more desirable, in view of the number of variables concerned, to eliminate the rods from consideration by using the rod-free portion of the fovea. The field should thus be limited to 1° or less.

The present experiment was undertaken because it seemed that clues to many of the puzzling problems in color vision might lie in a thorough understanding of the nature of saturation and its relation to brightness and hue. In the first place we ought to know, if possible, exactly how and to what degree different individuals differ from one another in sensitivity to color. For some years it has seemed probable that the ultimate explanation of the phenomena of color blindness will be found, not in terms of qualitative distinctions between a purely ficticious 'normal' group and several distinct 'abnormal' groups, but in terms of quantitative differences in degree of sensitivity. Thus color blindness would lie at the extreme of a frequency distribution of sensitivity.

In the past there has been only the vaguest notion of how the threshold for saturation varies with the level of brightness at which it is measured. One of the purposes of the present experiment was to determine the nature of this relationship. Thus there arises another reason for determining this function in terms of the retinal cones alone, for the Purkinje phenomenon complicates the saturation relationship by the inclusion of factors arising from the excitation of the rods.

A third problem, for which there has been but little quantitative data, is that of chromatic adaptation or minuthesis. It is recognized that a hue becomes less saturated as one continues to observe it, but the extent of the change and the exact form of the function relating the threshold with time are not known.

A second paper, to appear at a later date, will deal with the quantitative measurement of the minuthetic process and its probable physiological basis. In the present experiment this factor was kept constant by means of a technique which will be discussed in the next section.

The initial problem to be solved was that of an adequate experimental technique. Geissler's method, using pigment papers, was tried and found unsatisfactory. The Priest and Brickwedde technique was too elaborate, and it provided no temporal control. The apparatus and procedure to be described in the following section were the result of several months of preliminary work which already indicated the nature of the significant variables, and how they may be controlled.

Apparatus

There were three important requirements to be fulfilled in devising apparatus for this experiment: (1) an accurate means for varying the saturation from zero to some maximal value, a change which could be accomplished only with apparatus which would alter the proportions in a mixture of chromatic and white light without changing the total brightness of the mixture; (2) a means for equating the chromatic light and the white light in brightness at any chosen level; and (3) adequate control of minuthesis, a control which can be obtained by limiting the time of exposure of the stimulus, and by preventing dark adaptation during the intervals between exposures.

Figure 1 is a floor plan of the apparatus. Requirements (1) and (2) were met by building a rotating disc color-mixer which provided for continuous variation of the proportions in the mixture without stopping the rotating discs. There are several forms of apparatus now available for this purpose. The one chosen was patterned after that described by Dimmick (3). Instead of pigment papers, two monel metal discs (*M* and *N*, Fig. 1) were used. Each of these had two, symmetrically located, 90° sectors removed. When they were placed one behind the other on the mixer shaft, their angular relation could be varied between a position in which the open sectors of one disc were completely filled by the solid sectors of the other, and a position in which the open sectors of both discs were superposed. A beam of light from source *A* (Fig. 1) was reflected from the surface of these discs to the observer's eye. This beam was the white-light source. Light from source *B* passed through a Wratten filter (*D*) and then through the aperture in the mixer discs to the observer's eye. When the discs were rotated, these two beams were mixed and the observer saw a circular spot of light whose size was controlled by diaphragm (*K*), whose brightness was dependent upon the positions of the two sources with respect to the discs (and by a neutral wedge (*L*)), whose hue was controlled by the Wratten filter (*D*), and whose saturation was dependent upon the size of the open sector in the mixer discs. When the open sector was maximal, one-half the light was white light reflected from the surface of the discs and one-half was chromatic light transmitted through the open sectors. The saturation could therefore be varied between 0 and 50 percent of the maximal saturation available from the given filter and source of light.

The apparatus could be used as a flicker photometer by setting the discs so that the aperture was maximal (50 percent). Flicker judgments could then be made in the usual way by varying the intensity of one light source and the speed of rotation of the discs. The general level of brightness was obtained by the neutral filter (*L*) which affected the mixed beam, and the observer made adjustments to equality by means of a crank which moved source *B* on its track. Once the two lights had been equated by flicker at a given level of brightness, the total brightness remained constant regardless of the size of the aperture of the discs, because a change in the size of the aperture resulted in the addition of a certain percentage of one light and the subtraction of an exactly equal percentage of the other light (*i.e.*, a change was in *saturation* only).

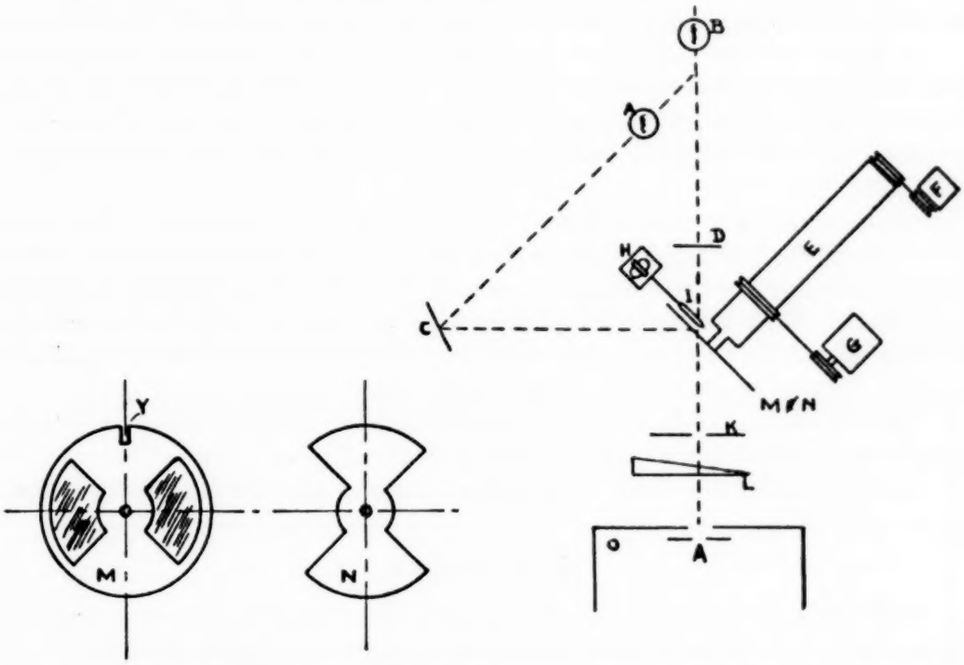

FIG. 1. Plan of apparatus. *A* and *B*, 500-watt lamps; *C*, white reflection surface; *D*, Wratten filter; *E*, color mixer; *F*, synchronous motor; *G*, motor for driving mixer; *H*, magnet; *I*, shutter; *K*, diaphragm; *L*, neutral wedge; *M* and *N*, sector discs; *O*, observer's booth; *Y*, stroposcopic slot.

Accurate measurement of the size of the aperture was obtained by the use of a stroboscopic device first described by Pfund (11). A slot (*Y*, Fig. 1) was cut in the rim of the larger disc on a radius of the disc. A beam of light from a projector was focussed on this slot. When the discs were in motion the light from the projector passed through the slot for an instant during each revolution of the discs. This light was reflected by a concave mirror onto a scale marked on the back surface of one disc. Since the light passed through the slot only once per revolution, it was always reflected upon the same portion of the disc, and the scale was seen as stationary regardless of the speed at which the disc were revolving. The size of the aperture could be measured to about 0.1 percent without stopping the mixer. This technique nullified errors introduced by back-lash and play in the color-mixer shafts.

The third requirement of temporal control was met by the use of a magnetic shutter (*I*, Fig. 1) placed in the same plane as the sector discs and directly behind them. This shutter was also made of polished monel metal. When it was 'closed' the beam of

chromatic light which normally was transmitted through the open sectors was cut off, and the polished face of the shutter reflected the white light exactly as though the size of the aperture were zero. When the shutter was 'open' it had no effect on the passage of light through the system. The magnet operating the shutter was controlled through a relay by an automatic timer.

The sources of light were two 500-watt, concentrated-filament projection lamps running on 115 volts. Their color temperature was about 2700° K.

Wratten monochromatic filters were used for the control of wave-length. The median wave-length of each filter was calculated from the transmission tables of the filters. The transmission value for each 10-mμ band was weighted in accordance with the visibility function, and the median wave-length was determined for the resultant values. The wave-lengths derived by this process are necessarily approximate.

In Fig. 1 the reflector (*C*) is a composition disc from a Macbeth illuminometer. It was used to reduce the intensity of source *A*. The transmission values of the Wratten filters are relatively low, and source *A* was much too bright. The use of the reflector (*C*) obviated the necessity for several reducing screens or for a less intense source of white light.

All apparatus was housed so that stray light was at a minimum. The subject sat in a booth (*O*, Fig. 1). With the exception of the housing around source *B*, which was painted a flat white to increase the intensity by reflection, all housing was painted a flat black. Since the light from source *B* passed through a Wratten filter before reaching the subject's eye, the slight selectivity of the white paint was deemed unimportant. The white surface was renewed from time to time.

The reflection curve for the monel metal mixer discs is approximately a horizontal straight line, indicating that the monel metal is nonselective.

An ink spot on a thin sheet of clear glass in front of aperture *K* provided a fixation point.

Procedure

Before the observer made a set of judgments with respect to saturation he equated the two lights in brightness, using the standard procedure of flicker photometry. The visual field was smaller than the two-degree field usually recommended, but this was necessary in order to prevent stimulation of rods. The source *A* (white light source) was placed in a position to give the required brightness, the sector opening was put at 50 percent, and the observer made a flicker equation. He controlled the speed of the discs (motor *G*, Fig. 1) with a rheostat, and the intensity of the chromatic light (*B*) with a crank which moved the lamp upon its track.

The motor (*G*) was then run at a speed well above that for critical frequency of flicker, the sector aperture was put at zero, and the shutter circuit was closed. When the shutter was 'closed,' the observer saw a 1° circular field of homogeneous white. When the shutter was 'open,' he saw the same field illuminated by the mixture of white and color whose proportions he controlled. He added chromatic light (at the same time automatically subtracting an equal amount of white light) until the field with the shutter open (the mixture) was just perceptibly different from the field with the shutter closed (the white). The observer was therefore making successive judgments by the method of average error. The direction of rotation of the motor (*F*) which changed the proportions in the mixture was controlled by the experimenter, and the observer varied the aperture in only one direction for a given judgment.

The sector was then opened somewhat more, so that there was a clear difference between the two fields, and the observer subtracted chromatic light until the mixture

was just perceptibly *not* different from the white. The average of these two settings was taken as a measure of the threshold. All measurements were in percent.

The rate of alternation of the white with the mixture (controlled by shutter *I*) was kept constant in this experiment. The time of exposure to the mixture was 1 sec. The time of exposure to the white was 3 sec. These temporal relations were decided upon after experimentation with times varying between 1 and 60 sec. Different temporal relations alter the constants in the equation describing the function, but not the form of the function.

Each observer made a flicker equation before each set of judgments at a given brightness level. This procedure was followed even when the observer repeated a set of judgments at one brightness level on consecutive days.

Adaptation to the level of illumination was complete at the time the judgments were made.

It has often been assumed that a large number of judgments must be obtained in the measurement of thresholds. Preliminary investigation satisfied the experimenter that this is not necessarily the case. With adequate control of the conditions under which observations are made, a single judgment from a trained observer is highly significant. The fatigue induced by visual work probably renders a single judgment a more reliable measure of the threshold than many judgments repeated one after the other. Figure 2 is a plot of a series of pairs of judgments for two observers (one 'normal' and one color-blind) taken over a period of two months. Each point is the average of two judgments, one of 'different' and one of 'not different.' It is apparent

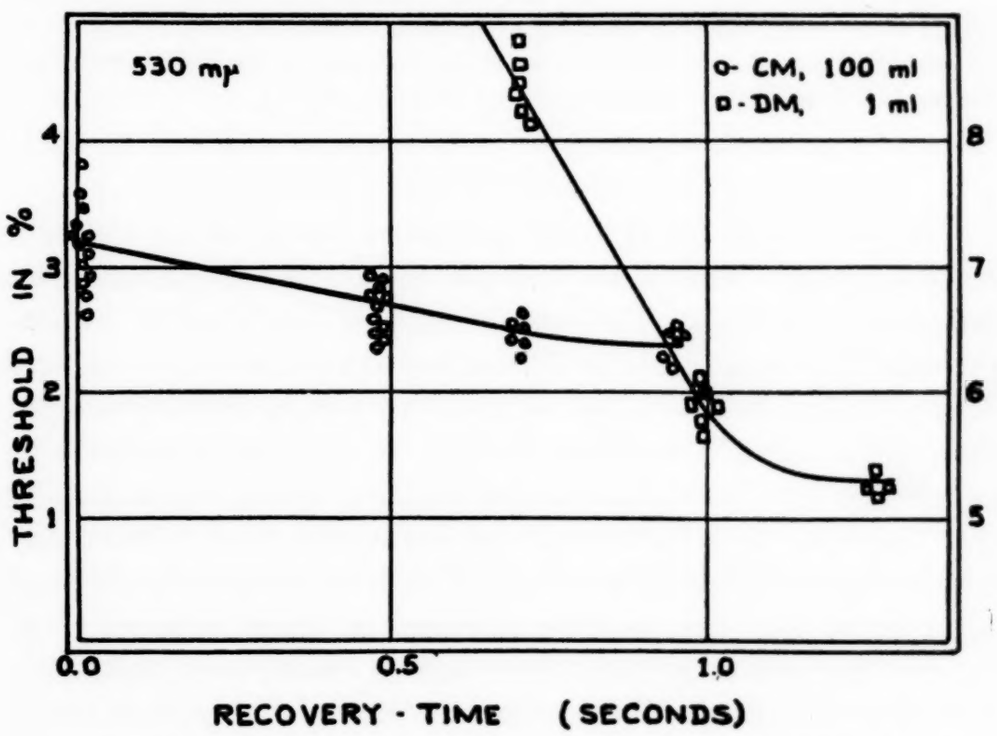

FIG. 2. Each plotted point is the average of one judgment of 'different' and one judgment of 'not different.' The points were determined over a period of 60 days. The scale of ordinates on the left is for CM; that on the right is for DM. 'Recovery time' signifies the period of stimulation with white light which was alternated with 1 sec. stimulation with the varying mixture of chromatic and white light.

that the variability is small. Consequently, unless some circumstance led the experimenter to believe that a given judgment had been markedly affected by extraneous conditions, only one pair, or at the most two pairs, of judgments were taken for a particular relationship. An adequate period of training was given each observer before experimentation began. The uniformity of the results constitutes the sanction for a procedure with few repetitions.

Eight observers were used during the course of this experiment. Two were partially color blind. The other six all passed the Ishihara test with no errors. Of the eight, only one (GB) was an inexperienced observer. Five of the remaining seven were either graduate students or members of the staff of the Harvard Psychological Laboratory. The other two (LG and CM) had both served previously as observers in psychological experiments.

The matter of fixation is a factor in the experimental technique which could undoubtedly be the source of large errors. It has become apparent since the experimentation was completed that a large illuminated surrounding field would have been a valuable addition to the experimental set-up, a fact which was not recognized before the experiment was undertaken. The surrounding field, if it were illuminated by the same intensity of white light as the stimulus field, would have lessened the necessity for completely accurate fixation, because the whole eye would then have been in a state of adaptation to the particular illumination in question. However, it is probable that significant distortion would only occur at brightnesses above those used in this experiment.

With this one exception the experimental procedure provided quite satisfactory control of the many variables involved. The most reasonable proof of this view is (1) the high degree of internal consistency of the data, and (2) the high degree of consistency of the data with other known facts of visual sensation.

Results

The threshold for saturation was measured at six different wave-lengths. The most complete data were gathered for the green (530 mμ). The reasons for this choice were: (1) The 530-mμ filter had a relatively narrow transmission band, and hence yielded a closer approximation to monochromatic light than did some of the other filters. (2) It had a high transmissibility (5 times that of the 675 mμ filter, for example) and thus the threshold could be measured over a relatively large range of brightnesses. (3) The wide range of individual differences, and the relative changes in these differences at various levels of brightness, were shown clearly with this filter.

Table I gives the thresholds in terms of the percentage of light of the different wave-lengths that it was necessary to add to white of the same brightness in order to provide a just perceptible difference between this mixture and the equally bright white light. The measurements were made at levels

TABLE I

LEAST PERCEPTIBLE SATURATION FOR FIVE WAVE-LENGTHS

The thresholds are in terms of the percentage of chromatic light which had to be added to white light in order that the mixture should appear just noticeably different from the white of exactly equal brightness which was used as a comparison stimulus.

	Obs.	Brightness in Millilamberts													
		.01	.02	.1	.2	.5	1.0	2.0	5.0	10	20	50	100	200	500
530 mμ	IK	10.75	6.45	3.34			2.28			1.77			1.83	1.97	2.40
	EGB		8.40	6.43			5.24			4.18			3.82		
	CM	18.40		7.90			4.95			3.30			2.58		
	DM			20.10			7.03			3.65			3.08	3.20	
	GB					26.70	16.70	9.63		4.30			4.58	5.93	
570 mμ	IK						33.50		18.89	15.40	13.42	12.03	10.90	10.10	
	CM						13.50			6.43			5.90		
	DM				32.80	18.90	15.70	11.91	8.90	7.30	6.07	5.78	5.26		
595 mμ	IK	21.40		4.50			1.93			1.35			1.48		
	DM			21.30			11.90			7.65		6.00	5.20	5.20	
675 mμ	IK	8.44	5.30	2.10			9.25			8.25					
	DM		32.00	21.65			8.40	7.00		5.75	5.43				
	GB						22.85	19.03		14.88	14.40				
445 mμ	IK	7.46		1.90			0.75			0.80					
	DM	7.58		2.15			0.93			0.83					
	GB			1.75			0.70			0.78					

of brightness varying between 0.01 and 500 millilamberts. The former figure is very nearly the lower limit for cone vision.

Figure 3 is a graphical interpretation of the data for 530 mμ in Table I. The curves have no mathematical significance. They are simply smooth curves drawn through the data.

It is obvious that the most marked effect of low sensitivity to color upon the threshold for saturation occurs at low brightnesses. The threshold for GB could not be measured at 0.1 ml. A mixture of 50 percent color and 50 percent white was not perceptibly different from 100 percent white. The same relation held for DM at 0.01 ml. On the other hand, the differences between the thresholds of the five observers at 100 ml. are extremely small. The rise in some of the curves at this point may be due to the lack of an illuminated surrounding field.

Figure 4 gives the data for three eyes at 570 mμ. Since yellow is the least saturated spectral color, it is not surprising that the thresholds should be relatively higher for this wavelength. A striking fact, however, is the relative position of the three observers as compared with their positions for 530 mμ (Fig. 3). IK, whose sensitivity to green was higher than

any of the five observers, is definitely less sensitive to yellow than either CM (normal) or DM (color-blind). His threshold at 1 ml. is more than twice as large as either CM's or DM's. While no extensive measurements were made, CM's sensitivity to red seemed to be almost identical with that of IK.

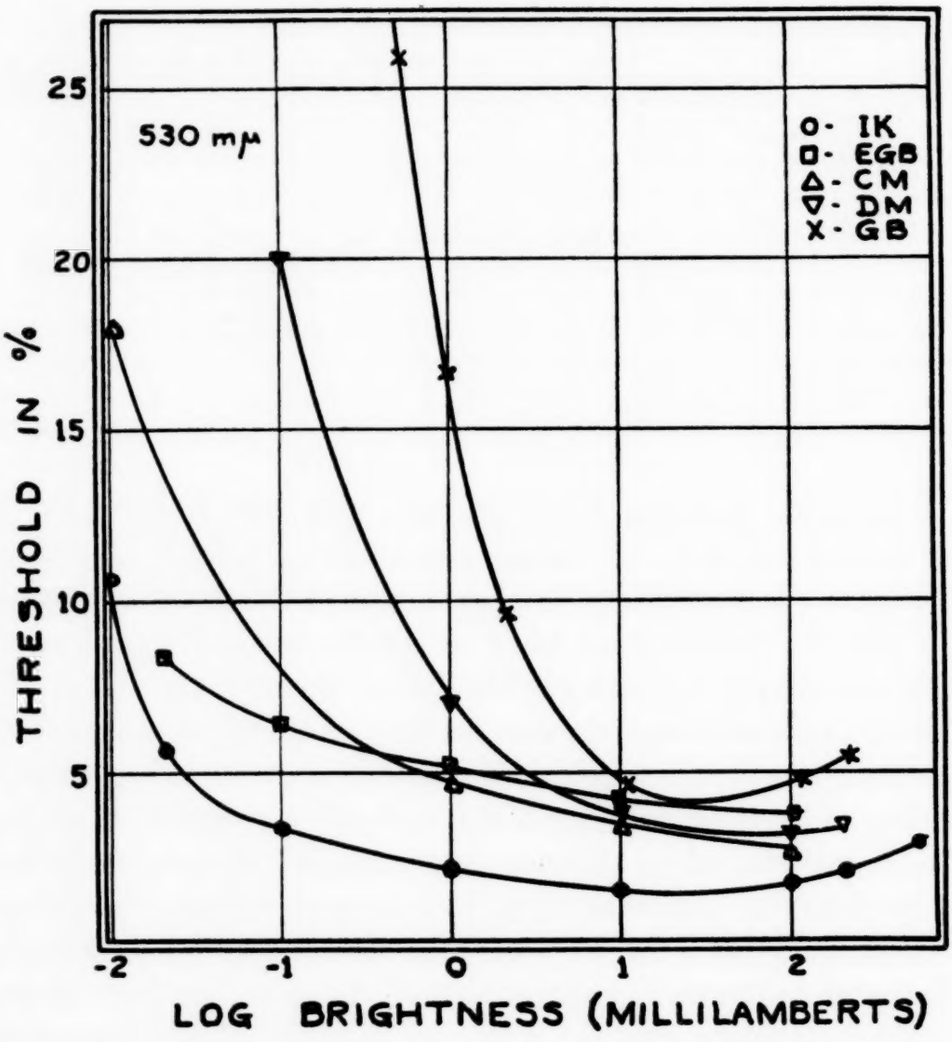

FIG. 3. Just perceptible saturation as a function of the level of brightness. DM and GB are color-blind.

There seems to be reason for the statement, then, that the relative sensitivity to different colors varies from eye to eye. High sensitivity to one color does not necessarily indicate high sensitivity to all other colors.

The data for 675 mμ, 595 mμ, and 495 mμ are similar to those for 530 mμ and 570 mμ, as will be seen from Table I.

The same large individual differences are everywhere apparent. With the 445 mμ filter, however, the differences between the thresholds for 1 normal and 2 color-blind observers are insignificant. This fact is explained, at least in part, by the fact

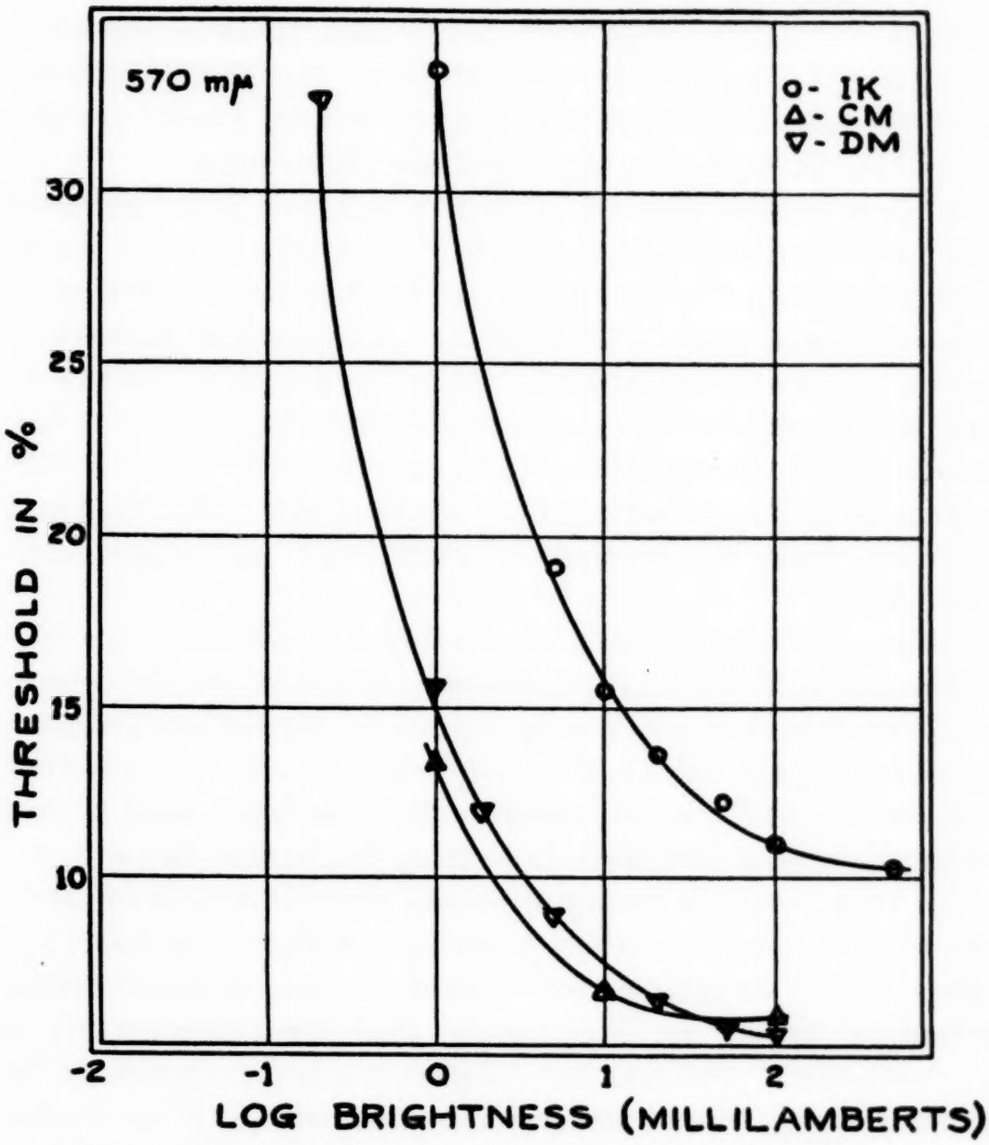

FIG. 4. Just perceptible saturation as a function of level of brightness.

that the thresholds were all so very low (under 1 percent) that relatively large differences would be masked by the technique of experimentation. Perhaps a less highly saturated blue or violet filter would make possible a clarification of this point.

In the following section we will consider the question of the importance of these data for the theory of color vision, and

the mathematical significance of the function relating the saturation threshold and brightness.

Discussion

It is difficult to discuss the very complex processes concerned in vision without simplifying them to an extent which is apt to be misleading. However, if the simplification is recognized as an intellectual tool, there need be no fear that it will mask important aspects of the phenomena.

Most modern theories of color vision are modifications of the two theories propunded during the last century by Hering and by Young. Today we recognize that these two theories are not necessarily incompatible. Theoretical discussions which are concerned with the retinal aspect of vision usually rely upon some form of the Young-Helmholtz theory. Those which are concerned with central process often find a modification of Hering's theory to be more suitable. The two may thus be made to complement each other with few incompatibilities.

Since the present discussion is devoted primarily to a consideration of the retinal processes involved in the discrimination of saturation, the Young-Helmholtz theory in its modern guise (**5**, **6**) provides a satisfactory corner-stone. In addition, for reasons which will become evident, we shall need to consider the retinal processes underlying brightness vision.

A very plausible theory of retinal function is that of Hecht (**6**, **7**). He suggests that brightness vision is primarily a function of two interrelated variables: the number of retinal elements [1] which are functioning, and the concentration of photochemical products resulting from the decomposition by radiant energy of a photosensitive substance (S) in the retina. This latter factor is assumed to be the determinant of the frequency of impulses in the optic nerve (although other processes are believed to intervene before the eventual excitation of the nerve fiber). That these two factors contribute to

[1] We are not concerned with the problem of rod vision. The present experiment was performed with retinal areas subtending retinal angles of one degree or less, so that there is little doubt but that the data pertain to cone vision exclusively. Thus the term 'retinal elements' here refers to cones, not to rods.

the same central function is not to be doubted. The central factor which serves as a basis for the discrimination of brightness is probably the total number of impulses arriving per unit of time per unit of stimulated area. The hypothesis of Hecht, which serves to explain the psychological facts of visual acuity and the discrimination of brightness with a remarkable degree of accuracy, is that the thresholds of the retinal elements vary, as for any large population, in a manner describable by the normal probability function. In his treatment of the experimental data Hecht employs the known facts of photochemistry with the result that his theory gains in plausibility because of the accuracy with which logically derived photochemical equations fit the extant data of many workers in the field.

If we assume, in accordance with the modern form of the Young-Helmholtz theory, that there are several types of retinal elements, and that each type possesses a slightly different spectral sensitivity, we can immediately suggest what the main factors underlying color vision might be. The discrimination of hue and of saturation, being dependent upon a central process, would be made possible by the discrimination of the *identity* of the retinal elements stimulated. For example, radiant energy having a wave-length of 530 mμ, equated in brightness to radiant energy having a wave-length of 650 mμ, would produce the same total excitation, although the energy values of the two stimuli would be quite different. The basis for discrimination between the two retinal processes, and therefore the basis of color vision, would depend upon the fact that the 530-mμ light would excite the three kinds of elements in certain ratios, while the 650-mμ light would excite them in different ratios.[2]

Saturation is the degree or amount of color. The saturation of the lights just mentioned would therefore depend upon the deviation of these ratios from the ratios for white light.

[2] This explanation cannot be simplified to the extent of talking about the relative *numbers* of elements stimulated, because the *degree* of excitation per element may vary. The 650-mμ light might excite 1000 elements and the 530-mμ light only 500, but if the concentration of photochemical products per element of the 1000 elements were one-half that per element of the 500, the total excitation would be the same in each case. For this reason the term 'ratios of excitation' must always be used.

This rather simple description of retinal function should not be far from the truth. It will be adequate, however, only if we take cognizance of the indisputable fact of individual variations in sensitivity to color. Collins (**1**, **2**) and Houstoun (**9**, **10**) have clearly demonstrated that indexes of sensitivity, such as color-mixture equations, when applied to a population, yield skewed probability curves. The data of this experiment show that sensitivity to saturation varies to a marked degree from eye to eye, even among 'normal' observers.

The obvious way to account for these differences in sensitivity would be to assume variability in the relative numbers of the three kinds of elements, or variability in the distribution of thresholds of the elements, or both. The Young-Helmholtz theorists have persistently avoided such assumptions, however, because of one or two obstacles which have seemed to them to be insurmountable. The first of these concerns the achromatic continuum.[3]

The proponents of the Young-Helmholtz view have appeared to find it necessary to assume that the three types of retinal cones must be present in equal numbers in order to account for the 'constancy' of white at all intensities. However, the necessity for this assumption is not at all apparent when we consider the modern experimental data on constancy produced by the Gestalt School.[4] At any rate, it is absurd to argue for equal numbers of elements so long as we remain unaware of the relation between the number of elements which are functioning at a given intensity and the degree of excitation per element.

If one admits the possibility of variation in the relative numbers of the three types of elements, or in the distribution of their thresholds (an eventuality quite to be expected in view of modern physiological data on populations), then the Young-

[3] Hering to the contrary notwithstanding, the matter of the perceptual uniqueness of white is no obstacle to a three-receptor theory of retinal function. The ease with which white can be obtained by the binocular mixture of complementaries has been adequately demonstrated (**13**, **14**).

[4] The fact of the Bezold-Brücke phenomenon is proof that there is some shift in the ratios of excitation at the higher intensities, although the nature of the shift is not the same as that under consideration.

Helmholtz theory becomes much more nearly adequate to the known facts of color vision.

The curves of Fig. 1 give a graphical picture of the variation from eye to eye in sensitivity to saturation. It is evident that the degree of sensitivity reveals itself most definitely in the range of brightness below 10 millilamberts. This fact is exactly what should be expected if sensitivity were a function of the relative numbers of the three kinds of elements, or of the distribution of thresholds among them. It is not at all unlikely that the threshold of a given element is dependent upon the concentration of Hecht's *S* in that element; and if this were true, subnormal sensitivity might be due to the presence of less than the normal amount of *S*.

Any explanation of the wide range of individual differences revealed by the data of this experiment must be in terms of degree, because the differences between IK and CM, two 'normal' observers, are quite as large as those between CM and DM, a 'normal' and a color-blind observer.[5]

Having considered the general aspects of our problem, let us attempt a specific analysis of the saturation relationship in terms of Hecht's theory of retinal process. Let us note carefully just what these data imply about retinal process. When the observer increases the percentage of 530-mμ light in the mixture—to take a specific example—he is increasing the energy of wave-length 530 mμ at the expense of the energy of the other wave-lengths. At the threshold the distribution of energy is presumably such that the ratios of excitation of the three elements produced by the mixture are just perceptibly different from the ratios produced by the white light of the same brightness. The total brightness, and therefore the total excitation, would be the same for the mixture as for the white alone, but, instead of the red-green-blue ratios of excitation representative of white, there would be some other, larger percentage of green excitation, and proportionately smaller percentages of red and blue excitation. This

[5] The data for all wave-lengths but 445 mμ (violet) reveal large differences in sensitivity between observers. The extremely low threshold for this filter may mask differences which nevertheless exist.

change in the ratios of excitation among the elements would be just sufficient to provide a basis for central discrimination.

In simple terms, then, it can be assumed that the discrimination of hue and saturation are special cases of the discrimination of brightness. Since the three elements vary only in degree of excitation, and this variation is the correlate of brightness, then it is clear that the variation in saturation and hue should also be cases of variation of differentials of excitation, *e.g.*, of brightness.[6]

If this assumption is true, and if the general scheme of Hecht's theory of the discrimination of brightness is true, there ought to be a close relationship between brightness, hue, and saturation in respect of retinal process.

Hecht (7) has recently revised his earlier assumptions regarding the nature of the function describing the discrimination of brightness, in order to account for the demonstrable fact that the rise in the curve at high intensities is dependent upon the experimental technique employed. If an illuminated surrounding field is used so that the whole eye is adapted to the brightness employed, the rise disappears and the threshold becomes minimal between 10 and 100 ml., remaining minimal thereafter regardless of the increase in intensity.

The equation now proposed by Hecht to describe these data is derived from the two basic equations which describe the reversible photochemical reaction $S \rightleftharpoons P + A$. It is

$$\frac{\Delta I}{I} = \frac{c}{a^2 k_2}\left(1 + \frac{1}{(KI)^{\frac{1}{2}}}\right)^2 \qquad (1)$$

in which c is a constant whose value depends upon the velocity of the reaction produced by the addition of ΔI to I, the constant a is the initial concentration of the light sensitive substance S (and is given the arbitrary value of 1), and K and k_2 are velocity constants. The exponents indicate the order of the $S \rightleftharpoons P + A$ reactions.

Figure 5 is the locus of this equation. The curve of Fig. 5 fits the recent data for the retinal cones throughout, and fits

[6] In terms of this hypothesis it becomes apparent why measurements of the threshold for saturation must be made under conditions where the total brightness of the field remains constant.

all the older cone data except at high intensities. Equations with other exponents (indicating monomolecular or bimolecular reactions) derived from the same basic equations yield curves which fit the data for the rods, and the animal data for Mya, Drosophila and the bee.

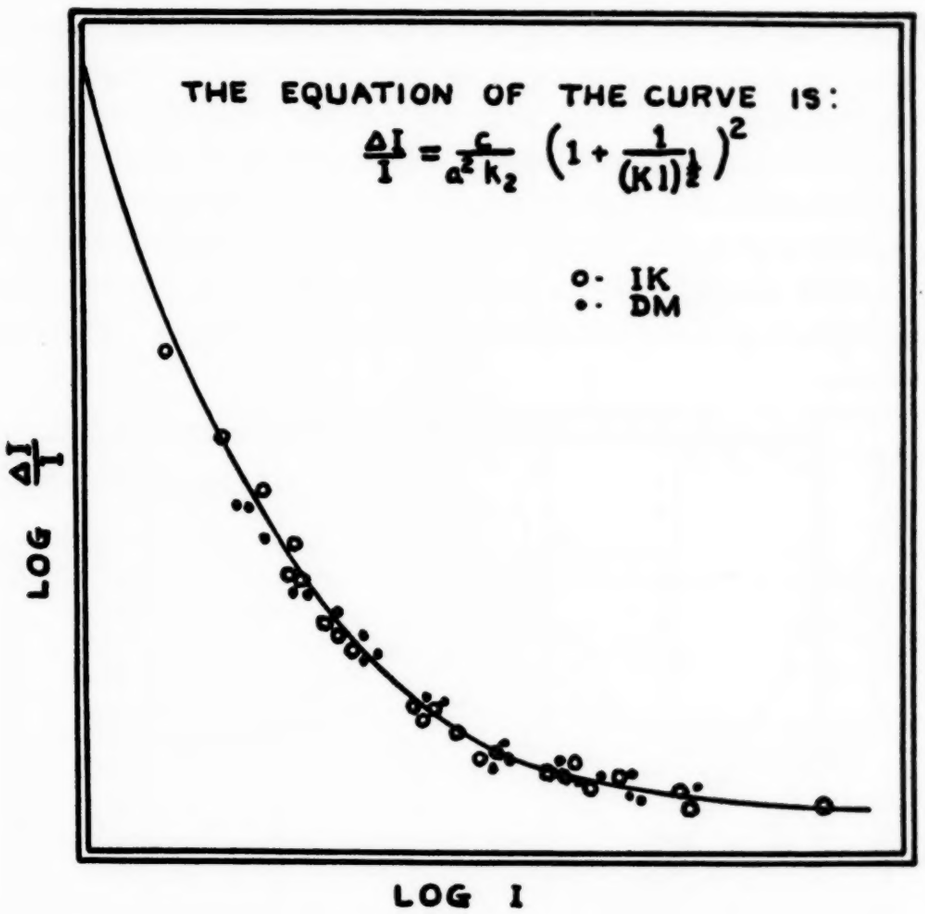

FIG. 5. The plotted points were experimentally determined. They are for five different wave-lengths. The position of the curve with respect to the ordinates has been shifted by changing the values of the constants for every wave-length and for each eye. The shape of the function is independent of the values of the constants. The open circles are for IK (normal), the closed circles are for DM (color-blind).

If the discrimination is a specific kind of brightness discrimination, we might expect a relationship between equation (1) and the data gathered in the present experiment. Since the threshold for saturation is expressed in percentage, it is indicative of the relative amount of light of a specific wave-length added to the white. It is, then, proportional to $\Delta I/I$.

Figure 5 provides a fairly conclusive argument for this assumption. The curve is the locus of equation (1). The ordinates are in terms of the logarithm of the threshold for saturation, at different wave-lengths, for IK (a 'normal' observer) and DM (a color-blind observer). The abscissæ are in terms of the logarithm of the brightness. The axes are labelled log $(\Delta I/I)$ and log I. The scales have not been inserted because the constant of proportionality relating the threshold for saturation and ΔI differs for different wave-lengths and for different eyes. Likewise the constants of the equation differ for different eyes, *but these factors affect only the position of the curve with respect to the axes; they do not affect its specific shape.* The scale of the ordinates in Fig. 5 covers about two log units, and the scale of the abscissa about four log units.

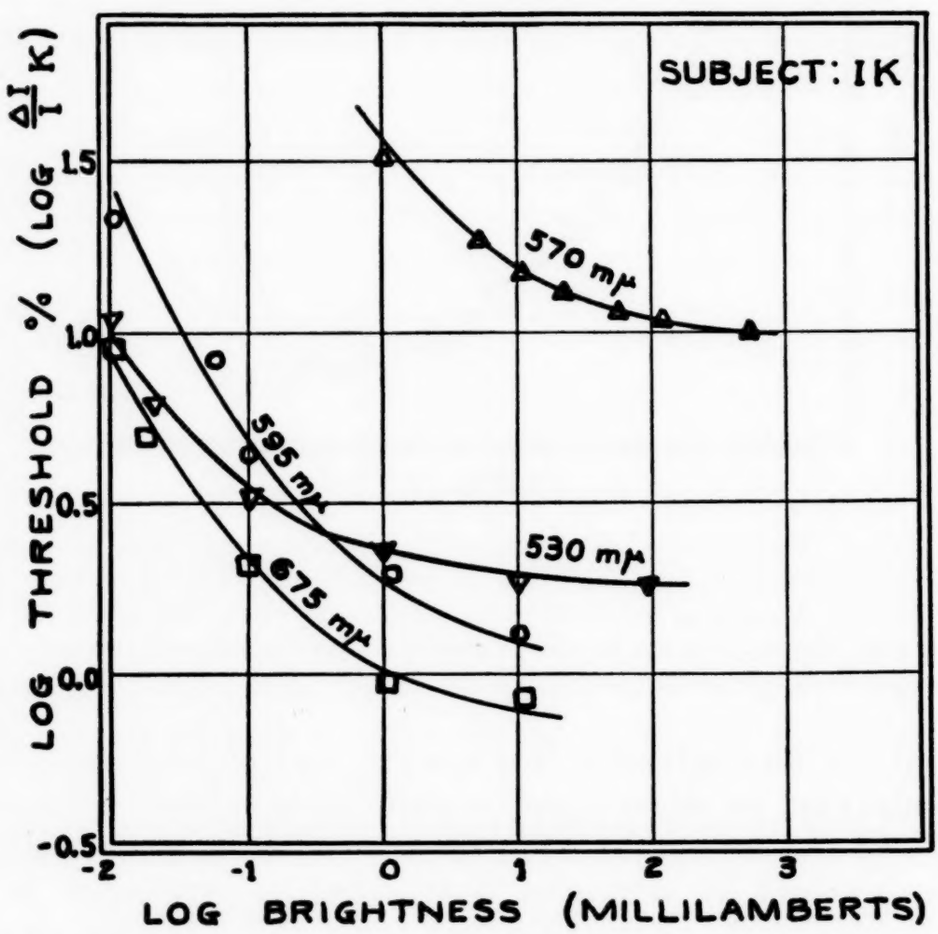

FIG. 6. The curves are from equation (1). The plotted points were experimentally determined.

Figures 6 and 7 are for these same points plotted to scale for each of the observers. Because of the relatively few points which were determined for a given wave-length, the fit of the curves of Figs. 6 and 7 is perhaps a little less obvious than in Fig. 5. However, when the several functions are combined as in Fig. 5, there is little doubt but that equation (1) describes the data adequately.

The points for brightnesses beyond the region where the threshold begins to rise at high intensities (*cf.* Fig. 1) have been omitted from Figs. 6 and 7. Whether or not this rise in the threshold for saturation with higher brightnesses is an artefact of the technique is a question which must await experimental verification. In view of the data of Wolf (15), of Hecht and Wald (8) and of Steinhardt (7) on the discrimination of bright-

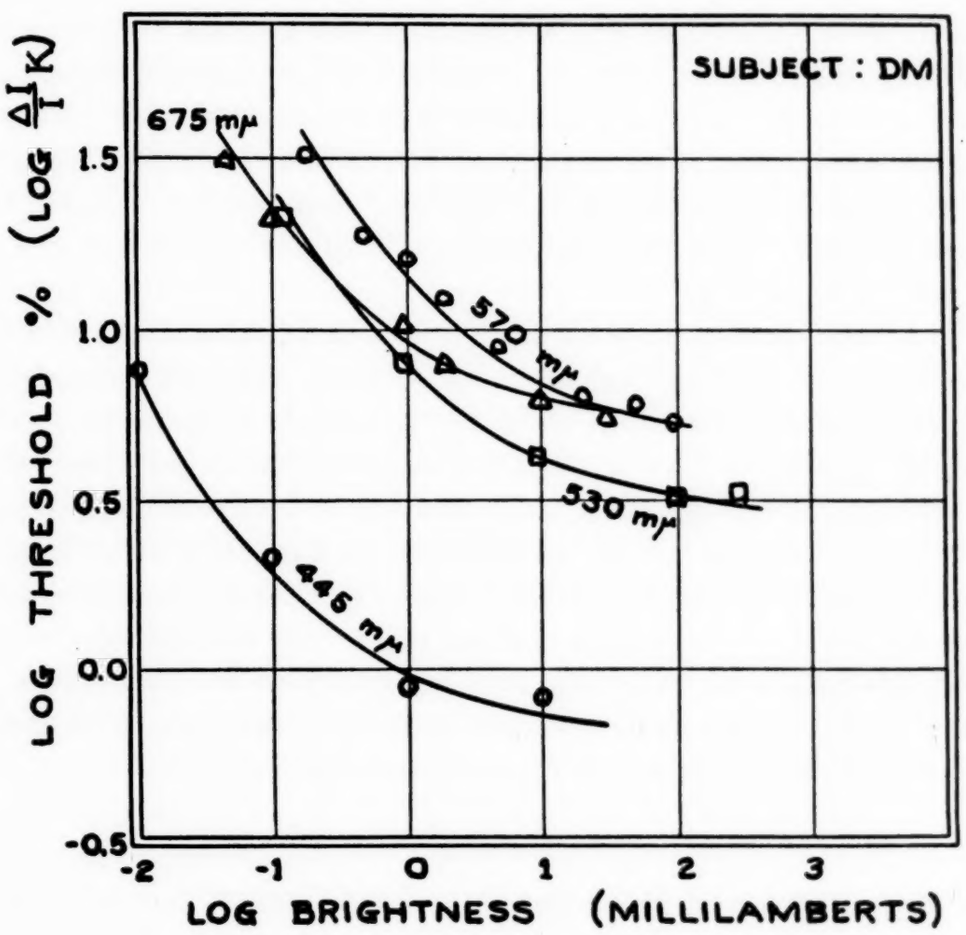

FIG. 7. The curves are from equation (1). The plotted points were experimentally determined. DM is color-blind.

ness, it seems likely that an illuminated surrounding field would cause this rise to disappear.

It is significant that the curve fits the data for DM's color-blind eye exactly as well as it fits the data for IK's 'normal' eye. The values of the constants are, of course, different, but that would be expected. These values are determined by two interrelated factors: the concentration of substances S, and the velocity of the $S \rightleftharpoons P + A$ reactions. These factors are interrelated because the velocity of a chemical reaction is dependent upon the concentration of the constituents of the reaction.

It is feasible, therefore, to suggest that the differences in threshold between IK and DM are dependent upon some quantitative aspect of the process, possibly the concentration of S. The equation (1) is expressive of a law for the discrimination of saturation which should prove to hold for all eyes. Variations in sensitivity are represented by changed values of the constants, and are matters of degree only. If further experimentation reveals that all forms of color defectiveness are adequately described by the law, then we shall have to admit finally that color blindness is a quantitative and not a qualitative affair.

All the data of Table I have not been fitted to the curve of equation (1). DM and IK were selected because more data were available for them than for the other observers. It is highly probable that, if the thresholds for the other observers had been determined at a large number of levels of brightness, the curve of equation (1) would fit these data fully as well as it fits the data for IK and DM. There is a strong presumption for the truth of a logically derived law which is consistent with related data when the law can be shown to hold for even a single case. The author is undertaking further experimentation in order to prove conclusively this generality.

Summary

Apparatus and technique have been devised for the measurement of the absolute threshold for saturation. The threshold has been measured at brightnesses ranging between .01

ml. and 500 ml. The data indicate that variations from the mode of sensitivity to saturation are the rule rather than the exception. Previous investigators, while often mentioning the possibility of a distribution of sensitivity among a population, have usually failed to recognize that an adequate theory of color vision must provide some means for the inclusion of such variation. It is evident that relative sensitivity to different hues varies from eye to eye. One individual may be super-sensitive to green, and less than normally sensitive to yellow (*cf.* the curves for IK in Figs. 3 and 4). These facts do not allow for a qualitative distinction between color blindness and normal vision. In terms of sensitivity, the classification of different 'forms' of color blindness is not likely to be very valuable. However, the Young-Helmholtz type of theory seems to provide an explanation of the retinal basis for this variability in discrimination if the probability of variability either in number of elements or in the distribution of thresholds, or in both, is recognized.

An analysis of color vision in terms of brightness vision can be made. Amount of excitation is assumed to be the retinal determinant of brightness. Hue is presumed to depend upon certain ratios of excitation among the different kinds of elements, and saturation upon the degree to which these ratios differ from those for white. The rough designation of saturation as amount of hue thus becomes an explicit assumption. In this way brightness, hue, and saturation are linked together by one comprehensive set of hypotheses concerning the photochemistry of the retinal process, and color blindness is plausibly explained in terms of quantitative variation in these same processes.

The experimental data are in reasonable accord with these hypotheses. The mathematical function descriptive of the discrimination of brightness is adequate to the data for the discrimination of the least perceptible saturation. However, judgment must be reserved regarding the behavior of the threshold above 100 ml. The contemporary theory of the retinal basis for visual acuity and for the discrimination of brightness thus gains in plausibility because the realm of its

applicability may be extended to cover these additional phenomena of color vision.

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THE SOMATIC EFFECTS OF STIMULI GRADED IN RESPECT TO THEIR EXCITING CHARACTER [1]

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Introduction

The purpose of this investigation is to study the effects of stimuli of an exciting character on certain physiological processes. The principal questions which the investigation seeks to answer may be stated in direct form as follows:

1. Will stimuli of an exciting character induce specific changes in heart rate, respiration, and the galvanic skin reflex, and will these changes be sufficient in amount to distinguish a period of stimulation from a period of non-stimulation?

2. What is the nature of the relation between quantitative variations of the exciting character of the stimuli and the amount of the induced effect?

3. Will the somatic effects increase or decrease as the stimuli are repeated from day to day, and will either the direction or amount of change vary with the strength of the stimuli?

The first task of the study was to select and grade a series of stimuli exhibiting the maximal range of exciting character. Presumably the best stimuli for this purpose are actual behavior situations in which the subject is a participant. The use of such stimuli in a laboratory experiment is obviously impracticable. This limitation was partially obviated by describing the behavior situations verbally and presenting them visually in printed form. To secure greater effect these stimuli were presented during deep hypnosis.

[1] From the Psychological Laboratory of the University of Chicago.

The Experiment

Stimuli.—Eighty-eight behavior situations exhibiting the maximal range of exciting character were described in as many short paragraphs. These were typed on separate cards. Each described an experience which it is presumably possible for anyone to have. The paragraphs were written for men, because at the outset it was planned that the experiment would be limited to male subjects. These paragraphs (hereafter referred to as stimulus situations, items, or simply stimuli) were addressed directly to the reader and were written in the continuous present tense; that is, they all had the suggestion that the experience was continuing and that it was not yet finished.

Twenty-nine university men were asked to evaluate the stimulus situations in respect to their exciting character. These judges were instructed in the use of the psycho-physical method of *equal appearing intervals* for placing the stimulus situations along a scale. The problem was put directly to the judge as follows, "If you think a situation described would have very little or no excitement for you if you should experience it, place the card in pile 1; if you think a situation described would have the greatest possible excitement, place the card in pile 8. Place other cards on the scale according to how exciting the situations would be if you should experience them." After sorting was complete the judges were directed to go through the piles and re-examine them to make certain that all cards were satisfactorily placed.

The stimulus situations were then scaled [2] and the agreement of the judges on the location of each item was measured. When these measures, scale value and ambiguity, had been calculated for the 88 items, the experimenter went through the list and selected 12 for use in the experiment. Three criteria were used in the choice of these items. First, there must have been agreement among the judges on the location of an item. Hence an item too ambiguous was disposed of to begin with. The second criterion was the scale value of an item. It was desired to have items about equally spaced along the scale. In the final selection, the items had the following values: .2; 1.15; 2.05; 2.5; 3.4; 4.10; 4.35; 5.1; 5.82; 6.65; 7.65; 9. The extreme measures were found by a method of extrapolation. As a third criterion, the experimenter eliminated those items in which there appears some recurring action such as rowing a boat. In preliminary experimentation it was discovered that some subjects resort to slight imitative movements which might be expected to interfere with the functions being studied.

The 12 situations, or items, together with key number, scale value, and inter-quartile range, are given on page 549.

Use of Hypnosis.—It is perhaps important at this point to give an explanation for the use of deep hypnosis in the experiment.

In the first place, if ideational stimuli of the kind previously described are given to subjects in a normal waking state they respond with a slight altering of somatic processes; there may be no detectable change. Certainly the magnitude of the response is by no means as great as in the actual behavior situation. In hypnosis, however, when the same stimuli are given, the effects are very pronounced. While the intensity of reaction may not be as great as in a behavior situation, it seems to approach that level of response.

A second and perhaps less vital reason for the use of hypnosis is the effectiveness of that technique in eliminating distractions in the sensory field and in the form of competing ideas. The usefulness of hypnosis is attested by Heilig and Hoff (11) who say that hypnosis "eliminates all spontaneous processes in consciousness," that "consciousness is limited to the idea-content given by the hypnotist."

[2] According to the method of L. L. Thurstone (14).

Key Number	Item	Scale Value	Interquartile Range
72	You are driving along a country road and come in sight of a flock of sheep grazing in a meadow. You stop and watch them. Some of them raise their heads and look at you.	.20	2.50
31	You are sitting in a formal garden on a stone bench alone watching a fountain spraying.	1.15	1.60
85	You are standing watching a sailor being tattooed. He is having an anchor tattooed on his arm.	2.05	1.95
49	You are witnessing a magnificent display of fireworks on the night of the Fourth of July.	2.50	1.25
61	You are standing so you can observe a seismograph. You see the swings of the instrument, and you know that an earthquake is going on somewhere.	3.40	1.50
26	You have cut your hand and there is a slow flow of blood that will not stop. Someone sends for a doctor, but he has not yet come.	4.10	1.50
3	You catch a woman in the act of stealing a pair of shoes. She is begging you not to report her to the police, saying that her children have no shoes. You doubt her story and keep an eye on her. She slips out of the store and down the street.	4.35	2.05
50	You are a dinner guest in the home of some people whom you don't know very well. You knock over a glass of water.	5.10	2.00
8	It is a very formal party and a friend has just informed you that you have a long rip in the seat of your trousers. You wonder how many people have seen it and spend your time trying to see that you are not further discovered.	5.85	1.60
79	You have been lowered one hundred feet below the surface of the ocean in an observation tube and are in no danger. In the clear water you can see a whale in battle with two large swordfish. It is a terrific battle. You keep watching.	6.65	1.70
66	You find yourself going down in quicksand when you try to cross a dry stream. You are successful after a hard fight in extricating yourself.	7.65	1.90
77	You are in Africa alone, when suddenly you are attacked by a leopard. You shoot and disable him, but he comes after you and you keep defending yourself with the bayonet on the end of your gun.	9.00	2.00

A third advantage in the use of hypnosis is that skeletal responses can be inhibited, while the more involuntary somatic processes, which this investigation purports to study, continue uninhibited. The presence of skeletal responses complicates the problem of measuring somatic responses and their elimination is of great practical importance to the experimenter.

The use of hypnosis raises the following question: Will our experimental findings be limited to the hypnotic condition, or will our empirical answers to the three proposed questions also be applicable to the waking state? There is no decisive evidence on which to base a judgment. In the absence of such evidence, this study assumes that these exciting stimuli will arouse essentially the same *kind* of somatic response for the two conditions although the amount of the response may differ materially for the two cases. Consequently we shall assume that the relation between the two variables studied will be essentially the same in character for both the hypnotic and the waking states.

Subjects.—The next problem was to find subjects who would go into deep hypnosis, upon whom the stimuli might be applied. Thirty-two subjects were examined in an

effort to find those suitable, *i.e.*, those who would go into a sleep sufficiently deep for the experiment. Out of the thirty-two, four went into a very deep sleep. It is with these four subjects that the experiment here reported is concerned.

Apparatus.—The measurements taken were concerned with changes in pulse rate, in respiration, and in the galvanic skin reflex. All recordings were made simultaneously on a photographic strip. Pulse rate was taken by means of an inflated cuff wrapped about the ankle. Only enough air pressure was kept in the cuff to show heart beats clearly on the developed film. Thus the subject could sit for a long period without the discomfort that comes with too much interference with circulation. A pneumograph was fastened about the chest to indicate changes in respiration. A string galvanometer was used to show changes in the electrical resistance of the skin. The instrument used in the present study was modified in accordance with the hook-up of Darrow (**9**). The advantages of the arrangement have been enumerated by him.

The electrodes of the galvanometer were zinc with a coating of a paste of kaolin powder and zinc sulphate solution. One of the electrodes was applied to the palm of the hand and the other to the back; they seemed to work satisfactorily. The string came quickly into balance and did not require frequent adjustment due to chemical and thermal changes in the electrodes. During a part of the experiment one of the electrodes was applied to an area rendered indifferent either by the use of iodine or by pricking the skin, but this practice was discontinued. The iodine was found to be an irritant in connection with the zinc sulphate-kaolin paste and pricking the skin repeatedly with a needle was unsatisfactory.

A kymograph of the camera type was used for taking records. An electric motor fed a strip of bromide paper past the lens of the camera at a very slow rate, approximately six inches per minute. The lamp back of the string in the galvanometer cast a shadow of the string against the aperture of the camera and at the same time furnished enough light to expose the film. Shadows from the pointers of pulse and respiration tamborus were simultaneously cast on the film along with that of the string of the galvanometer. A metronome interrupted the source of light every second making a time line on the record. Minute markings across the lens of the camera caused millimeter lines to appear lengthwise of the developed film strip.

Procedure.—The subjects were hypnotized in a room adjacent to the experimental room. Preliminary work showed that persons who first saw the experimental room could not be hypnotized. The forbidding appearance of the apparatus was no doubt largely responsible. After deep hypnosis had been induced the subject was asked to move into the experimental room and be seated at a table.

The hypnotized subject next memorized the twelve stimulus cards. He was checked by the experimenter from time to time during the experiment to see that all essential points were retained.

While each stimulus was being memorized, a substitute card with the stimulus shortened to a phrase was also exposed. The shortened cards only were used subsequently. By this means the stimulus could be presented quickly. Preliminary experimentation showed that when the original stimulus cards were used, bodily changes got under way before the reading of the card was finished.

The subject was now ready to begin the first day's experimentation. The apparatus was attached. When adjustments were complete the subject was told to fall into a much deeper sleep and was given a period of time to quiet down. Subjects were told to avoid movements of the arms and legs. They were told further that if the apparatus caused pain, this fact was to be reported promptly.

Each of the 12 stimuli was given once at each sitting. The order of presentation of the 12 stimuli was varied systematically from day to day. There were 12 stimuli, and hence 12 positions in which they might be placed. An effort was made to perfect a plan whereby each stimulus had occupied each position by the time the experiment was complete for any one subject. For example, in arrangement *a*, stimulus 49 was in the 4th position; in arrangement *b*, the 8th position; in *c*, the 2nd, and so on. A perfect plan whereby each stimulus occupies each position is not possible when there are 12 stimuli and 10 days of experimentation.

Each subject began the experiment with a different arrangement and took the remaining ones in order. Thus the first subject began with arrangement *a* and continued through *j*. The next subject began with arrangement *b*, continued through *j* and ended with *a*.

When any experimental day began the subject was told that he was about to be shown the short stimulus cards again. He was told that he would actually *have* the experiences described. The statement was emphasized that these experiences would be 'very vivid, very real.' This exact terminology was used consistently.

The subject was told that the experience would continue for 30 seconds, or until a signal from the experimenter. As the technique of presentation of the stimuli was finally worked out the subject sat with eyes closed except for the moment when it was necessary for him to open them in order to see the words on the short card. This procedure was followed because it is known that the galvanic skin reflex is closely associated with motor behavior, and by the means indicated, the amount of muscular effort in receiving the stimuli was reduced to a minimum. It was necessary simply to open the eyes, and having perceived one line on the card, to close them again. The only words spoken by the experimenter after the presentation of the first stimulus card were, "The first card, please" (later, "The next card, please"), and, at the end of 30 seconds, "That will be all."[3]

A rest period of 30 seconds was introduced between stimuli. No records of somatic changes during the rest periods were taken. The experimenter observed that during these periods there was almost no change in galvanic skin activity. Respiration was very regular.

Records for four 30 second periods of non-stimulation were taken each day as a standard of reference. One of these was taken each day before any of the stimuli had been given, and one after all stimuli had been given. The subject was not aware that these two records were being made. The other two were interspersed among the stimuli and their location was varied from day to day. For these two the subject opened his eyes, saw the word 'Blank' on a card, and closed them again. He had been instructed that when this happened he was to have simply no experience.

Tests were repeated for ten days.[4] The 12 stimuli were given twice to two subjects on three days. This was done as a convenience to these subjects who had to come a considerable distance to take part in the experiment.

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[3] After the experimental period was complete, subjects were told to "Let these experiences slip from your mind and think of them no more." They were given the usual suggestions about feeling well and absence of eye strain. They were usually awakened in the experimental room.

[4] When the subject had completed the ten days of experimentation he was tested to see how much of the experiences through which he had gone had been retained. The depth of hypnosis in which the subjects had been may be inferred from the fact that all of them had to relearn the stimulus paragraphs in the waking state. They did not recall having seen the cards before.

Number of Records Available.—At the close of an experimental day, 16 half-minute records had been taken. For subjects who completed ten days of experimentation there were therefore 160 such records available, or 640 for four subjects. According to the plan there were 40 records for each stimulus because all four subjects were given each stimulus on ten occasions. Thus each value for each stimulus was the average of 40 measures; the standard (period of non-stimulation) was an average of 160 measures.

Actually, however, the number of records taken was less than 640, for the following reasons: (1) One subject was able to complete but seven days of experimentation. (2) There was an occasional loss of a record due to failure of the camera to feed the film properly. (3) Two film strips, each containing 16 records and each the work of one day's experimentation, were lost by overdeveloping. These, unfortunately, represented the first day's work with two subjects. (4) Two subjects were asked to go through the experimental series in the waking state. They had just finished their day's experimentation while hypnotized and were very sleepy. While supposedly awake, they seemed to fall back into a light hypnotic trance, and the experimenter was so uncertain of their exact state that he could not use the records.

In spite of the losses, there were retained 518 records. Records were measured in 8 different ways. Descriptions of these measures will be given later.

Results.—There was one measure each for pulse and the galvanic skin reflex. For respiration, however, the records admitted of a greater number of analyses and were accordingly studied in six different ways. Descriptions of the various measures will be given wherever the names are not self-explanatory.

The numerical data are given in Table I. In the first row are found the scale values for the various stimuli. Below these are the corresponding values for each of

TABLE I

AVERAGE EFFECT OF STIMULI

Measure	Standard	Scale Value										
		.2	1.15	2.05	2.50	3.40	4.10	4.35	5.10	5.85	6.65	7.65	9.00
Pulse....	78.4	81.4	81.1	83.3	83.9	81.7	83.5	82.8	83.9	84.6	85.0	85.9	85.4
Galvanic skin reflex	.8	2.3	2.6	4.7	3.6	3.4	3.5	3.0	3.4	4.0	3.9	6.1	6.1
Respiration													
A.....	18.2	19.0	18.0	20.6	20.6	21.9	21.2	19.8	20.5	22.3	22.7	21.9	21.6
B.....	35.0	45.8	50.6	49.7	61.4	53.0	53.4	55.8	54.6	57.4	70.0	80.4	80.4
C.....	.53	.64	.61	.63	.68	.71	.68	.66	.68	.70	.74	.76	.75
D.....	5.35	7.65	7.80	7.25	8.98	7.23	7.87	8.25	7.47	7.97	9.96	11.4	11.0
E.....	.66	1.38	2.21	1.93	2.35	1.39	2.26	2.17	1.96	1.99	2.70	3.73	3.32
F.....	.69	1.51	1.75	2.34	2.78	1.71	2.45	2.58	2.45	2.42	3.14	4.35	3.73

the eight measures. The 'standard measure of non-stimulation' for each of the eight measures is given in the first column. These values will be referred to hereafter as the standard. Each of the values in the table is the average for all subjects for all experimental days. These data furnish the answer to questions one and two as stated in the Introduction.

In order to study the effects of stimulus repetition, the data for those days for which there were complete records were grouped temporally into two series. Experimental days 2, 3, and 4 compose the first series, and days 5, 6, and 7 compose the second series. Figure 1 shows these two series plotted for each measure. The large circles

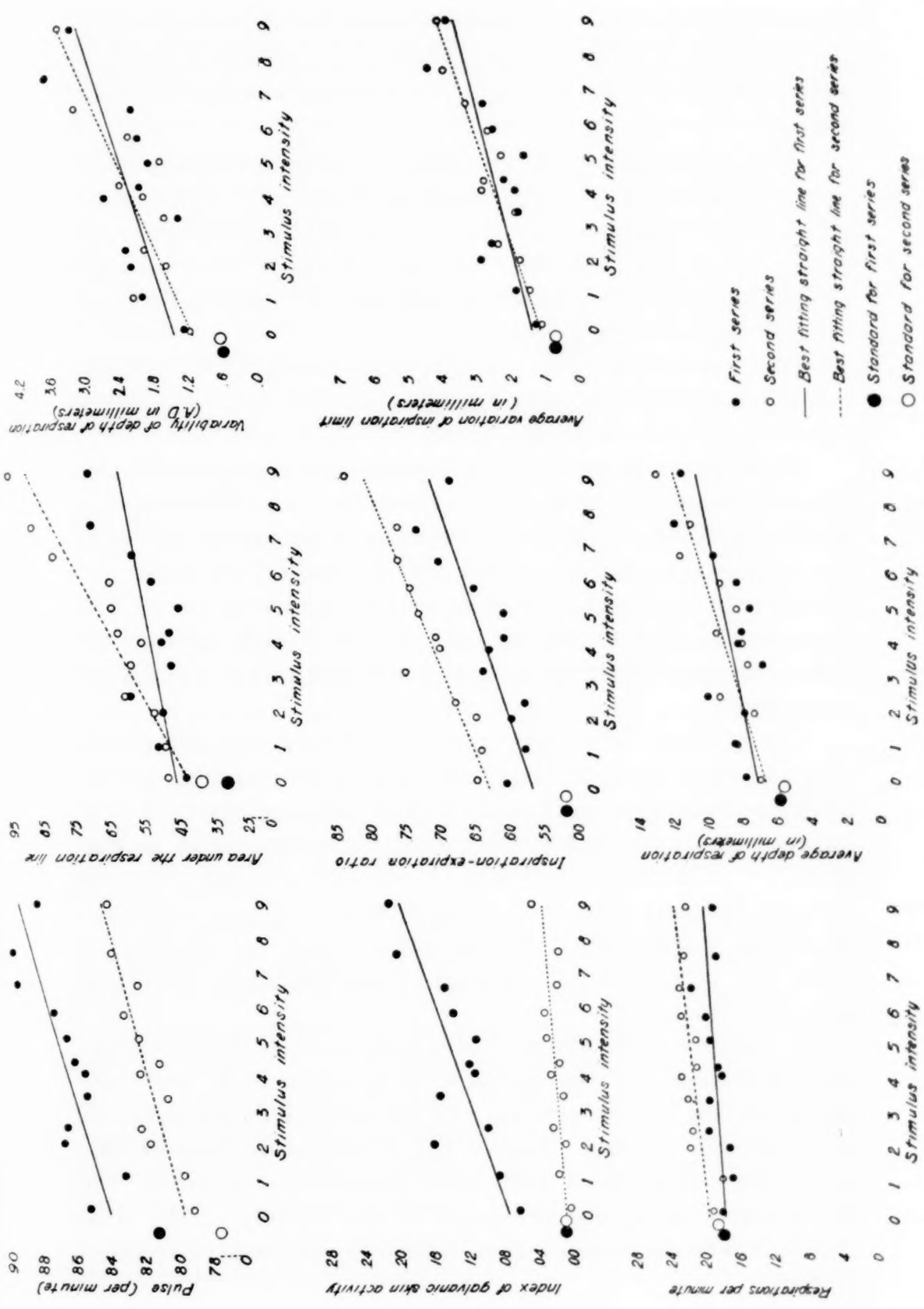
Variability of depth of respiration (A.D. in millimeters)
Average variation of inspiration limit (in millimeters)
Stimulus intensity
• First series
○ Second series
—— Best fitting straight line for first series
---- Best fitting straight line for second series
● Standard for first series
○ Standard for second series
Area under the respiration line
Inspiration-expiration ratio
Average depth of respiration (in millimeters)
Pulse (per minute)
Index of galvanic skin activity
Respirations per minute

FIG. 1. Showing the effects of stimulus repetition.

denote the standard values, and the small circles represent the values for the various exciting stimuli. The black circles represent the values of the first series, and the open circles the values of the second series. The lines shown are the straight lines of best fit.[5] The difference in size of the two series of values represents the effect of repetition.

1. *Pulse.*—Each of the exciting stimuli increased the heart rate in comparison with the standard (Table I). (This statement is also applicable to each of the four subjects with the exception of one stimulus for one subject.) The increase ranged from 2.7 to 7.5 beats per minute. Corresponding percentage values are 3.4 and 10.

The rate tended to increase with the strength of the exciting stimulus, and the relation between the two variables is approximately linear in character.

The effect of repetition is a decrease in heart rate and this occurs throughout the scale. (See Fig. 1.) The average heart rate for the stimuli of series one is higher by 4.8 beats per minute than for series two. The standard for series one is higher by 3.5 beats per minute than for series two. The slope of the best fitting straight line is slightly greater for series one than for series two, the numbers being .34 and .30 respectively.

The findings here reported are in substantial agreement with the early work of Angell and Thompson (**1**) who, on the basis of their own work and that of others, conclude that increase in heart rate is associated with increase in mental activity. The recent review of Darrow (**7**) concludes that an increase in heart rate is to be expected from long sustained ideational stimulation. Dodge (**10**) found an increase in pulse rate related to an increase in excitement in an actual behavior situation.

2. *Galvanic Skin Reflex.*—Measures used in the investigation of changes in the galvanic skin reflex took into consideration the initial resistance of the subject at the time the stimulus was applied. Brown (**4**), Cattell (**6**), Darrow (**8**), and Lauer (**13**) have used this percentage measure, the denominator being the resistance of the subject at the time

[5] Fitted by the method of least squares in such a way that errors in the y-axis are minimized.

of the application of the stimulus, and the numerator being the amount of change in resistance in response to stimulation. Thus, a subject who shows a high resistance at one time may be expected to respond to stimulation with a greater change in resistance than when his resistance is lower. All measures in the study were of this character. These measures have been multiplied by 100 to accord with current practice in dealing with this index of galvanic skin activity.

The averages for all subjects for each stimulus are given in Table I. All of the exciting stimuli increased the measure in comparison with the standard. The same statement is true of each of the four subjects with the exception of one stimulus for one subject. The increase ranged from 1.5 to 5.3. Corresponding percentage values are 187 and 663.

Values tended to increase with the strength of the stimuli; the relationship is non-linear. Two of the most exciting stimuli elicited unusually strong reactions.

There is no change in the standard with repetition (Fig. 1); there is, however, a pronounced change for the exciting stimuli. The degree of change increases with the strength of the stimulus, and may be said to be highly specific, and not general as in the case of heart rate.

The galvanic skin reflex has almost disappeared in the second series and the slope of the line of best fit is so slight that it differentiates poorly between the more and the less exciting stimuli.

3. *Respiration.*—The respiration curves were studied in many different ways. First of all, counts were made of the number of respirations per minute (Table I, line A).

A second measure was the area under the respiration curve (line B of Table I). This measure was taken by the following method: Considering the points on the record where expiration stopped as a base, a polar planimeter was used to measure the area under the curve. This was done with considerable accuracy, so that even though the size of the photographic record was small, a retracing of the irregular surface revealed a discrepancy which amounted to but 1 to 2 percent of the

total area. Values were in square inches. All numbers were multiplied by 100 for convenience in handling.

A third measure was concerned with the length of inspiration time as compared with the length of expiration time. The former divided by the latter gives the so-called inspiration-expiration ratio (line C).

As a fourth measure, the average depth of respiration was computed (line E).

For a fifth measure, the variability of depth of respiration was computed (line E). To do this it was necessary to get the average deviation for each record for each subject for each day. The average of these gave an index of the variation in height of the respiration curve.

The sixth measure of respiration was concerned with variation of the inspiration limit. The term 'inspiration limit' refers to the point on the record where inspiration ceases and expiration begins. The altitude of this point varies for successive respirations during excitement and the measure here used is the average difference in successive points during the application of a particular stimulus. The measure has been used effectively by Bass (**2**).

A. Number of Respirations per Minute.—In this measure (Table I, line A) eleven of the twelve stimuli showed an increase over the standard. (This was the case also with 43 of the 48 individual records.) The range was from .2 less than the standard to 4.5 greater. Corresponding percentage figures are −1 and 25.

There was a slight increase in the measure as the strength of the stimulus was increased. The relationship is approximately linear.

Repetition tends to increase the number of respirations per minute. This is true for all stimuli, and, in general, the more exciting the stimulus the greater the increase. The standard is slightly increased also, but there is a greater increase for the stimuli. The explanation of these increases is probably that as the experiment progressed there was less restriction on respiration, and consequently fewer occasions when the breath was held for short periods. In the computations no account was taken of these 'holds.'

B. Area under the Respiration Line.—This measure shows an increase above the standard for all stimuli (Table I, line B). (There is a similar increase also for all individuals.) The range is from 10.8 to 45.4. Corresponding percentage figures are 31 and 129.

Values tend to vary directly with the strength of the stimuli, though the relation is non-linear. There are relatively smaller increments for the stimuli near the center of the scale and relatively greater increments for the more exciting stimuli at the upper end of the scale.

Repetition tends to increase the area under the respiration line. This is the case for the standard and for eleven of the twelve stimuli. There is a strong tendency for the increases to be proportional to the strength of the stimuli.

C. Inspiration-expiration Ratio.—This measure has been studied chiefly by those who were interested in its use as an indicator of deception.[6] It is probably true that all cases of deception are exciting, and that the greater the deception the greater the excitement. It seemed possible that all exciting situations might be accompanied by a change in the ratio, and for that reason it was introduced here.

The results from the measure are shown in Table I, line C. It will be observed that the standard is .53. All stimuli caused an increase over the standard and this was true of all individual results as well. The range of increase over the standard was from .08 to .23. Corresponding percentages are 15 and 43.4.

The ratio increases with the strength of the stimuli, and the relationship is by inspection linear.

Repetition does not affect the standard, but results in an increase for all of the stimuli. The straight lines of best fit for the two series are almost parallel; there is a slight tendency for the stimuli at the upper end of the scale to cause a greater ratio in the second series.

D. Average Depth of Respiration.—The change in average depth of respiration with increase in stimulus intensity is seen in Table I, line D. The standard is 5.35; and all stimuli show increases over this amount. (Individual results also show

[6] See Benussi (3) Burtt (5), and Landis and Gullette (12).

this to be true in 47 out of 48 cases.) The range of increase is from 1.88 to 6.05. Corresponding percentages are 35 and 113.

There is a tendency for depth of respiration to increase with stimulus intensity, though the results are not proportional.

Repetition has but a small effect on the standard, diminishing it slightly in the second series. With repetition there is a tendency for the values to decrease for the less exciting sitmuli and to increase for the more exciting ones. For the first series the slope is .18, and for the second it is .28.

E. Variability of Depth of Respiration.—The results of the computations for this measure appear in Table I, line E. All stimuli cause an increase over the standard; this statement is true also for 47 of the 48 individual results. The range of increase is from .72 to 3.07. Corresponding percentages are 109 and 465.

There is a clear indication that as intensity of stimulus increases there is a corresponding increase in irregularity of depth of respiration. However, the relationship between these variables is not proportional.

The effects of repetition are not clear. The standard remains about the same. As the stimuli are repeated variability is decreased for the less exciting stimuli and increased for the more exciting stimuli. The slopes of the straight lines of best fit are .30 and .42 for the first and second series respectively.

F. Average Variation of Inspiration Limit.—All stimuli show an increase over the standard which is .69. The range is from .82 to 3.66, the percentage figures being 119 and 530.

There is a tendency for this measure to increase with the strength of the stimuli, and the line of best fit is a straight line. Six of the twelve points on the graph fall very close to the line.

Repetition does not affect the standard; it affects the stimuli only slightly. Seven of the eight most exciting stimuli are increased and the four least exciting are decreased. The slopes are .24 and .31 for series one and two respectively.

Conclusions

From the foregoing results it seems possible to draw the following conclusions:

1. Heart rate, the galvanic skin reflex, and the six measures of respiration are increased by exciting ideational stimuli during hypnosis. The application of even the least exciting stimulus gives effects which are clearly distinguishable from that of a period of non-stimulation.

2. The increase in effect is roughly proportional to the strength of the exciting stimulus. In some cases the relationship is linear, but in others, due particularly to the pronounced effect of the more exciting stimuli, it is non-linear.

3. As the stimuli are repeated, heart rate is decreased and the decrease is about the same throughout the scale; there is also a corresponding decrease in the standard. Respirations per minute and inspiration-expiration ratio by contrast are increased, and the increase is approximately the same throughout the scale. The standard for these, however, remains unchanged. There is a decrease in galvanic skin activity and the decrease is proportional to the strength of the stimulus. Again by contrast, there is an increase in area under the respiration line and the increase is proportional to the strength of the stimulus. The other measures show a decrease in the effectiveness of the less exciting stimuli and an increase in the more exciting. All standards remain unchanged for these measures.

With the repetition of stimuli there is an indication that the processes studied become less variable. The residuals of the straight lines of best fit (Fig. 1) were computed for all measures and it was found that they are much less for the second series than for the first. The ratios of the first to the second for each measure are as follows: pulse, .56; galvanic skin reflex, .39; respirations per minute, 1.04; increase in area under the respiration curve, .82; inspiration-expiration ratio, .58; average depth of respiration, .80; variability of depth of respiration, .76, and average variation in inspiration limit, .46. The average ratio is .68, which means that residuals are on the average but two-thirds as great in the second series as in the first. This decrease of variability is probably due to the disappearance of 'general excitement,' and the arousal of more specific responses to the stimuli.

The writer is greatly indebted to Professor Harvey A. Carr for supervision of the problem from the beginning, but especially for help in the final preparation of the manuscript. Professor L. L. Thurstone gave advice on methods and made suggestions about the measures to be used. Dr. C. W. Darrow very greatly helped with the apparatus; he built a special bridge of his own design and installed it in the galvanometer, and from time to time assisted when difficulties were encountered.

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INDIVIDUAL DIFFERENCES IN EASE OF CONDITIONING

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It has long been known that individuals differ in the ease with which they form conditioned responses. Pavlov (**6**) has analyzed the temperaments of his dogs on the basis of their modes of reaction in conditioning situations, and several investigators in this country have attempted to relate ease of conditioning and other measures of individuality (**3**), (**5**), (**10**). Several relevant studies are described in Razran's reviews (**7**), (**8**), (**9**). In view of these interesting leads it seems desirable to consider more fully the possible significance of conditioning as an objective measure of behavioral differences.

With an almost complete absence of standardization of such important variables as the strength of the unconditioned stimulus, the interval between the conditioned and unconditioned stimuli, the distribution of trials, the technique of measurement, and the choice of the reflex to be conditioned, the derivation of general conclusions in regard to individual differences in conditionability becomes difficult indeed. This report is limited to a consideration of the conditioned eyelid response as obtained from college students under specified circumstances. While the conclusions reached need not necessarily apply to other conditioning procedures, they serve to illuminate the interrelationships within one conditioning situation and to account for some of the apparent inconsistencies in the literature.

Experimental Procedure

As described in another report (**4**), 63 subjects (45 men and 18 women) were given 100 conditioning trials consisting of a flash of light of low intensity followed after 400 milliseconds by a puff of air delivered abruptly onto the cornea.

The resulting eyelid closure was recorded photographically. Conditioning was evidenced by the appearance of responses following the light, anticipating the air-puff. The training series was divided into two one-hour periods on consecutive days and was followed in each case by a short extinction series. Most of the subjects returned at a later date for a measure of their retention of the conditioned response as reported elsewhere (**4**). Only the first two training periods will be considered here.

Measures of Ease of Conditioning and their Reliability

There are at least four ways of indicating an individual's relative susceptibility to conditioning. The traditional measure, which we have called the *criterion score*, is exemplified in Mateer's (**5**) study of normal and dull children. The subject is given a number of reinforced trials sufficient to bring him to a prescribed criterion, *e.g.*, a designated number of conditioned responses. He is then arbitrarily considered 'conditioned' and his ease of conditioning is determined by the number of reinforced trials which were necessary for him to attain the criterion.

A corollary of this is the *frequency* measure. A fixed number of reinforced trials are given and the subject's relative susceptibility to the procedure is determined by the number of conditioned responses he has given during the training period. A third indication may be gained from measurement of the *amplitude* of the conditioned responses given. Those subjects whose conditioned responses are of generous proportions are evidently more amenable to the conditioning procedure than those who give only a slight response. A fourth measure, though somewhat more indirect, is the *latency* score which is obtained by measuring the average latency in milliseconds with which each subject's conditioned responses follow the conditioned stimulus. As conditioning progresses this latent period tends to decrease and those subjects who condition most readily tend to give responses of low latency.

As far as the writers are aware, the reliability of these measures has never been reported. The traditional descrip-

tion of the evanescent nature of the conditioned response would not lead one to expect very great consistency. However, our coefficients (see Table 1) indicate that fairly satisfactory reliabilities may be established.

TABLE 1

RELIABILITIES OF MEASURES OF CONDITIONING

$N = 63$

	Day 1 – Day 2	Segment – Segment *
Frequency	.66±.05	.86±.02
Amplitude	.75±.04	.88±.02
Latency	.51±.06	.60±.06

* The segmental correlation counterbalances practice effects to some extent by comparing the middle segment of trials (Trials 26–75) with the first and last quarter of trials (Trials 1–25 and 76–100). The correlations are not stepped up.

It is obviously impossible to obtain the usual type of reliability coefficient for the criterion score as there is only one score available. But by correlating this score (the number of the trial on which the fifth anticipatory response was given) with the total frequency of the anticipatory responses given during the 100 reinforced trials of the training period a correlation of $r = -.79 \pm .03$ was obtained. This suggests that the rapidity with which the first few conditioned responses are given is a rather good indicator of the frequency of the responses to follow. The frequencies of the conditioned responses given by our 63 subjects on the first experimental day correlated with their frequencies on the following day $r = .66 \pm .05$. The amplitudes of these same responses on Day 1 and Day 2 correlated $r = .75 \pm .04$. The average latencies of Day 1 and Day 2 correlated $r = .51 \pm .06$. If instead of pairing the first half of the trials against the second half in this manner, the middle trials (Trials 26 to 75) are correlated with the first and last trials (Trials 1–25 and 76–100) (which seems a legitimate procedure in dealing with a progressive change of this kind) these correlations rise to $r = .86 \pm .02$ for frequency, $r = .88 \pm .02$ for amplitude and $r = .60 \pm .06$ for latency.[1] The correlations are not stepped up.

[1] With the omission of one very divergent case the coefficients for the latency measure rise to $r = .56 \pm .06$ for Day 1 versus Day 2 and $r = .75 \pm .04$ for segment versus segment.

A further measure of reliability may be obtained by correlating the frequency of the anticipatory responses given during the training period with the number of conditioned responses given during experimental extinction. As Pavlov observed, "It is clear that the more vigorous a conditioned reflex, the greater the number of unreinforced repetitions necessary to bring about complete extinction." The correlation between the frequencies of the anticipatory and extinction responses given by our subjects was $r = .64 \pm .05$, a coefficient which is very probably lowered by the restricted range of the extinction series (only ten extinguishing trials were given). Bernstein (1) used a procedure similar to ours and obtained a correlation of rho = .88 between these two variables. The agreement of these results makes it apparent that conditioned responses need not necessarily be inconsistent and unreliable.

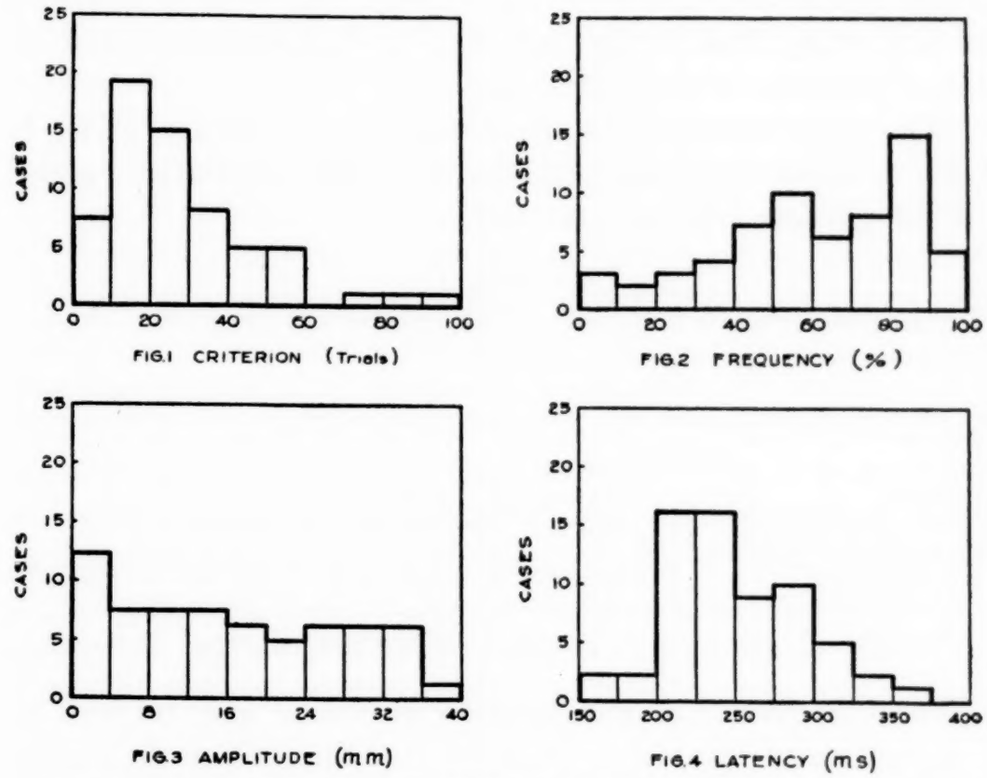
Individual Differences in Ease of Conditioning

One of the strictures against basing theories of human behavior upon the facts of conditioning experiments is the commonly reported finding that many human subjects do not condition. Our experiments show that, while individual differences are large, the number who do not condition at all under appropriate circumstances of experimentation is very small indeed. None of our 63 subjects failed to give at least one anticipatory conditioned response during the course of 100 double stimulations, and, in over half the cases, well-stabilized conditioning was obtained.

In Fig. 1 is given the distribution of the criterion scores. Fifty-four of the 63 subjects had given five anticipatory responses before the end of the first training period of 50 conditioning trials and all but one of the other nine attained the criterion during the second session. The positive skew is pronounced. Disregarding the one subject who did not fulfill our requirement, the remaining 62 subjects required from seven to 90 trials to reach the criterion. The mean was 25 trials.

As might be expected the distribution of the total frequencies of anticipatory responses, shown in Fig. 2, is skewed in

the opposite direction to that for criterion scores. Those subjects who reached the criterion rapidly had a large number of conditioned responses before the training session was completed and those who attained it slowly necessarily achieved comparatively low frequencies. The frequencies, expressed in per cents of total possible, ranged from 2 to 95 per cent with a mean of 62.



FIGS. 1, 2, 3, 4. Distributions of Individual Differences in the Ease of Formation of Conditioned Eyelid Responses. Each figure represents the distribution of measures from 63 subjects during 100 conditioning trials.

The average amplitudes of the anticipatory responses given by each subject are shown in Fig. 3. In a possible range of from zero to 40 mm averages of from 1.3 mm to 37.2 mm were found. The mean was 16.6 millimeters. It is evident that a less sensitive recording device would have failed to detect the conditioned responses of some of the subjects. While the distribution of amplitudes is almost horizontal, there is a slight positive skew, *i.e.*, there are more subjects who yield responses of small amplitude than of large. There are 12 subjects whose conditioned responses averaged less than 4 mm

on the records, at an amplification of about four times the movement of the lid. With less sensitive devices these subjects would have been reported as non-conditioners.

Figure 4 presents the average latencies of the anticipatory responses given by each of the subjects. In a possible range of from zero to 400 milliseconds a dispersion of from 152 ms. to 367 ms. with a mean of 251 ms. was obtained. These scores are an expression of the promptness with which each subject responded to the light and anticipated the unconditioned stimulus which followed.

The inter-relations of these four measures are given in Table 2 along with their relation to reflex sensitivity, which will be discussed in the next section.

TABLE 2

INTER-CORRELATIONS OF MEASURES OF CONDITIONING AND REFLEX SENSITIVITY

	Criterion	Frequency	Amplitude	Latency
Criterion				
Frequency	−.79±.03			
Amplitude	−.43±.07	.63±.05		
Latency	.43±.07	−.54±.06	−.15±.08	
Amplitude of unconditioned response	−.28±.08	.47±.07	.55±.06	−.13±.08

$N = 63$ in all cases except the criterion measure which one subject did not attain.

Total frequency of anticipatory responses may be seen to be significantly related to each of the other three measures. Those subjects who gave a large number of conditioned responses during the training period attained the criterion quickly as shown by the correlation of $r = -.79 \pm .03$. Their responses were not only frequent but of large amplitude, $r = .63 \pm .05$, and the greater frequencies also tended to be accompanied by shorter average latencies, $r = -.54 \pm .06$. Those subjects whose anticipatory responses were large tended to reach the criterion rapidly, $r = -.43 \pm .07$, but their responses were only slightly shorter in latency than those subjects with small anticipatory responses, $r = -.15 \pm .08$. Conditioned responses of short latency were more frequent in those cases where the criterion was fulfilled in relatively few trials, $r = .43 \pm .07$.

On the basis of these distributions two tentative conclusions seem justified. With the conditioning procedure employed in this experiment it is relatively easy to obtain conditioned eyelid responses in college students. While wide individual differences in ease of conditioning may be expected eyelid closure may be readily conditioned in most subjects and a 'non-conditioner' would be quite unusual. There is no evidence to support Pavlov's theory of conditioning 'types.' None of the distributions shows the bi-modality which Pavlov suggests.[2]

It is unfortunate that the distributions presented above cannot be directly compared to those obtained in other studies. Unless the experimental procedures employed are identical in all the numerous important details it is impossible to compare the ease of conditioning of two different groups of subjects even though the same reflex is being conditioned in both cases. The frequency and criterion scores are especially susceptible to differences in experimental technique which might facilitate or impede the progress of conditioning. Differences in the sensitivity of recording devices affect not only frequency scores but also measures of amplitude. Latency distributions depend on the length of the interval between the conditioned and unconditioned stimuli and on the extent to which the conditioning has been carried.

An excellent illustration of disparity in distributions of ease of conditioning may be obtained by comparing the results of this study to those found by Bernstein (1). Bernstein's subjects were divided into several groups to determine the influence of temporal factors in the conditioning of the eyelid reflex and only the two groups in which the conditioned stimulus preceded the unconditioned stimulus by 500 ms. and 300 ms., respectively, will be considered here. These subjects, 23 in all, were given 50 consecutive presentations of an auditory stimulus of low intensity followed by a slight electric shock on the skin near the eye. Their differences in number of anticipatory responses given during these conditioning trials are

[2] It should be noted that most of Pavlov's comments apply more particularly to the formation of conditioned discrimination involving selective inhibition. Our experiments have not dealt with such phenomena.

shown in Fig. 5. The distribution has a marked positive skew.

If our 63 subjects are similarly distributed on the basis of their number of anticipatory responses given during the first

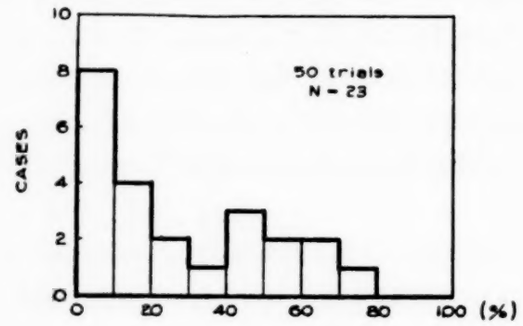


Figure 5

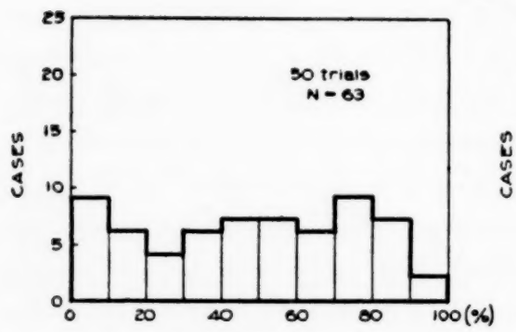


Figure 6

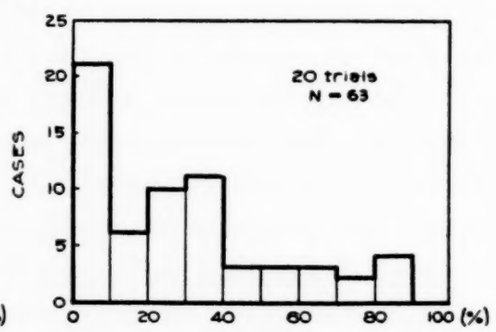


Figure 7

FIGS. 5, 6, 7. Distributions of Individual Differences in the Frequency of Conditioned Eyelid Responses in Two Investigations.

FIG. 5. Frequency of conditioned eyelid responses to sound based on shock. Data from Bernstein (1).

FIG. 6. Frequency of conditioned eyelid responses to light based on reflexes to an air-puff. Our data. Figure 7. Same, but earlier in the series of trials. Note the similarity between the distributions of Figs. 5 and 7.

50 conditioning trials a somewhat rectilinear distribution is obtained, as shown in Fig. 6. Our group showed much greater evidence of conditioning at this point than did Bernstein's. If our subjects are again distributed, this time on the basis of their frequency of anticipatory responses given during the first 20 conditioning trials, a distribution is obtained (Fig. 7) which is very comparable to Bernstein's. As far as the records show our group were as well conditioned in 20 trials as were his in 50.

In all probability no real difference in ease of conditioning of the eyelid reflex existed between Bernstein's group of sub-

jects and ours. However he used an unconditioned stimulus (shock) which was perhaps somewhat less naturally efficacious than the puff of air employed by us. Furthermore it is not unlikely that his pneumatic method of recording was somewhat less sensitive than ours and in this event our frequencies would tend to be augmented by responses of small amplitude which his apparatus would not register. These two discrepancies in experimental procedure could easily account for the varying results obtained in our two studies and they well illustrate the dangers which are implicit in comparisons of this kind. It is evident of course that distributions derived from the conditioning of different reflexes are even less comparable.

The Relation of Ease of Conditioning to Other Measures

In order to establish more clearly the identity of the trait, ease of conditioning, we attempted to relate it to certain other measures. For the most part these relationships were disappointing.

In order to check Mateer's findings in regard to intelligence and ease of conditioning the Thorndike Aptitude test ratings of 53 of our subjects were correlated with their conditioning scores. The correlation of the Thorndike ratings with frequency of conditioned responses was $r = .12 \pm .09$, with average amplitude, $r = .14 \pm .09$, and with average latency, $r = -.22 \pm .09$. It should not be overlooked that these low correlations may have been forced by the restricted range of talent in intelligence.

Simple finger reaction time scores were obtained from 30 of our 63 subjects.[3] If ease of conditioning were in any way a function of reactivity or motor excitability one would expect it to correlate with reaction time. However this variable seemed entirely unrelated to the conditioning scores. When related to total frequency of the conditioned responses the correlation was $r = .19 \pm .12$, with average amplitude the correlation was $r = .13 \pm .12$, and with average latency $r = .05 \pm .12$. Schlosberg (**10**) also measured the reaction

[3] The writers are indebted to Mr. Norman Sears who obtained the reaction time scores of these subjects.

time of his 20 subjects and attempted to relate it to the ease of conditioning of the patellar reflex. The correlation was low but positive, $r = .38 \pm .13$.

Berreman and Hilgard (**2**), using the sway technique of Hull, measured the susceptibility to oral suggestion of 16 of our subjects. The correlations they obtained with the conditioning measures all ranged about zero. Schlosberg was also unable to correlate these two variables. Evidently the influences exerted by the conditioning procedure and the prestige type of suggestion are not related.

It is a Pavlovian axiom that ease of conditioning is definitely related to reflex sensitivity: the more active a reflex the more readily it may be conditioned. As shown in Table 2 our correlations conformed to this expectation. Reflex sensitivity was measured by presenting the unconditioned stimulus (puff of air) without the conditioned stimulus at intervals during the conditioning period. The average amplitude of these unconditioned responses correlated with the criterion score, $r = -.28 \pm .08$, with the frequency of the conditioned responses, $r = .47 \pm .07$, with their average amplitude, $r = .55 \pm .06$, and with their average latency, $r = -.13 \pm .08$. There is also a reflex to the conditioned stimulus (light) distinguishable from the conditioned response, present both before and during conditioning. Its amplitude furnishes an additional measure of reflex sensitivity, correlating $+.41$ with the reflex to the air-puff, and similarly ($+.44$) with the amplitude of conditioned responses.

The relationship between ease of conditioning and sex cannot be established adequately from our data because of the small number of our subjects. Our 18 women subjects showed a slightly greater tendency to condition than did the men but the differences were not significant.

Summary

1. Measurements of conditioned eyelid responses have been found to be sufficiently reliable to justify comparisons of susceptibility to conditioning with other measures of individual differences. Frequency and amplitude are more reliable than

latency. The number of trials required to reach a criterion has been shown to be a corollary of the frequency measure and closely related to it.

2. Wide individual differences are present among human subjects in the ease with which they form conditioned responses. None of our 63 subjects failed to give at least one conditioned response during the training series of 100 reinforced trials. The criterion of five conditioned responses was reached in a mean of 25 trials.

3. Distributions showing individual differences in ease of conditioning of the eyelid reflex are without the bi-modality which Pavlov's type theory might predict.

4. Intelligence, finger reaction-time, and responses to prestige suggestion are not significantly related to ease of conditioning as measured in this investigation.

5. Ease of conditioning of the eyelid response is definitely related to reflex sensitivity, as measured by the responses to the unconditioned stimulus.

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SENSORY CONDITIONING

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Introduction

Preliminary Statement.—The present study of the conditioned response differs from practically all previous investigations inasmuch as most of the previous studies have been concerned with the conditioning of motor and glandular responses. The purpose of our experiment was to determine whether or not the intensity of sensory and associated verbal responses could be modified by training of the conditioned response ('CR') type. The CR training procedure ('Tr') was carried out under 4 different conditions in order to measure the influences of certain factors on the results, and to obtain some data on the rival theories of learning held by the centralists and motor psychologists. The 4 formalized conditions under which the Tr was carried out were (1) mere attention Tr, (2) attention and verbal process Tr, (3) attention and muscular tension Tr, and (4) attention and electric shock Tr. The investigation was suggested by certain changes in the apparent intensity of sensations which were observed in 2 of the writer's experiments on the conditioned eyelid reaction and by the results of Hartmann and others on the possibility of increasing the intensity of sensations by simultaneously stimulating other sense organs. The CR experiments of Bernstein (1) and Kelly (9) are also related to the results of the present study.

In my 1922 experiment on the conditioned eyelid reaction (2; 3; 4), an electric shock applied just below the eye called out unconditioned eyelid reactions, and a sound stimulus was given simultaneously with this shock-stimulus-and-eyelid-reaction in the Tr procedure. The physical intensity of the shock remained the same throughout the experiment, and at the beginning of the experimental period the shock alone

seemed to the S's to be of the same intensity as the shock in the shock-sound pattern. But after the shock and sound had repeatedly occurred together in the Tr procedure, the shock alone seemed weaker than the same physical shock in the shock-sound pattern (**2**, 192–193). The S's said the shock alone now felt weak and lacking in something; and after the Tr, the time of winking to the shock alone was slower than the time of winking to the shock-sound pattern. Although the shock alone, compared with the same physical shock in the shock-sound pattern, seemed weak and peculiar to the S's, the sound alone, compared with the same physical sound in the shock-sound pattern, seemed quite natural at all times. Similar observations have also been made by Bernstein (**1**), and there is apparently no satisfactory explanation of these results.

In a later experiment by the writer on backward conditioned eyelid reactions (**5**), the S winked naturally for a period of 2–4 hrs., and a sound stimulus was given immediately after each of the natural eyelid reactions. There were 17,727 repetitions of these Tr stimuli for the 8 S's used. In the latter part of the Tr period, when I gave the same sound stimulus alone, conditioned eyelid reactions did not occur in any regular fashion. In these CR trials, the S's generally had no impulse at all to wink, and in many cases they did not even know that the sound stimulus had been given alone without their winking. This experiment showed that a connection between an auditory stimulus and an eyelid response is generally not formed when the auditory stimulus is given immediately after the eyelid response in the Tr procedure.

But one observation was made in the above experiment which has a bearing on the present problem of sensory conditioning. After the auditory stimulus-and-response had repeatedly occurred immediately after the winking stimulus-and-response in the Tr, the presence or absence of the eyelid stimulus-and-response made a difference in the apparent intensity of the auditory response. To several of the S's the sound alone appeared weaker than the same sound when it was immediately preceded by a natural eyelid reaction. The

intensity of the auditory response had apparently been conditioned to the organic pattern of the preceding eyelid reaction, and the eyelid reaction seemed to have acquired the ability of increasing the intensity of the immediately following auditory response. It is possible, however, that before the Tr began, some reflex connections may have existed between the facial pattern of the eyelid reaction and the tension of certain muscles in the middle ear.

The other experimental result which influenced the procedure used in the present study was the finding of Hartmann (**6**; **7**; **8**), Kravkov (**10**; **11**), and others that the intensity of a sensory response may be increased by the simultaneous stimulation of other sense organs. Hartmann (**8**, 814) suggests that "If one may hazard a generalization, it seems that no receptor operates in isolation, but that the perceptions primarily mediated by a single modality are supplemented and modified by stimuli simultaneously affecting all the other sense organs." The results on the inter-relations of the senses are of theoretical importance apart from the problem of the present experiment.

General Plan of the Procedure Used in the Present Experiment.—The general plan of the procedure used with each individual S included the 3 following parts.

A. The Test Before CR Training Procedure ('test before Tr').—We first measured the natural influence of a sound ('So') on the apparent intensity of a light ('L') response and the natural influence of an L on the apparent intensity of an So response. In each trial, the intensity of the 2nd of 2 successive L's was compared with the intensity of the 1st, or the intensity of the 2nd of 2 successive So's was compared with the intensity of the 1st. If the intensities of 2 successive L's were being compared, an So stimulus was given simultaneously with the 1st or 2nd L; and if the intensities of 2 successive So's were being compared, an L was given simultaneously with the 1st or 2nd So. Each of these 4 combinations of L and So stimuli was used the same number of times.

The test before and the test after Tr were made in exactly the same way, and they are sometimes referred to as the 'testing procedure.'

B. The CR Training Procedure ('Tr').—The L and So stimuli were given together a number of times, and 1 of the 4 groups of S's was used in each of the following 4 Tr procedures; (1) S merely paid attention to the L and So stimuli as they were repeatedly given together (attention Tr); (2) In addition to paying attention to the simultaneous L and So stimuli, S alternately repeated the words 'light' and 'sound' while the L and So were present ('verbal Tr'); (3) In addition to paying attention to the L and So, S gripped a hand dynamometer in each hand while the L and So were present ('tension Tr'); and (4) In addition to paying attention to the L and So, S received an electric shock while the L and So were present ('shock Tr').

The differences between procedures (1), (2), (3), and (4) above were the only systematic variations in the experiment which were used with different S's.

C. The Test After CR Training Procedure ('test after Tr').—As stated above, the test after Tr was made in exactly the same way as the test before Tr, and the purpose of the 2 tests was to measure the changes in the influence of an L on an So response and the influence of an So on an L response which may have resulted from repeatedly giving the L and So together under the systematic conditions of the 4 Tr's described above. The various factors in the experimental situation were controlled in such a way that an accurate measure of these influences was obtained.

Apparatus

During the experiment E and S were in different rooms, and S could not hear any sound from E's room. The apparatus in the 2 rooms was connected by a cable of 16 wires.

The Three Stimuli.—The 3 stimuli used were an L, an So, and an electric shock, and the physical intensity of each stimulus could be readily changed. The 3 stimuli were given mechanically on all occasions.

The Light Stimulus.—The source of the L was a 3.8 volt General Electric Mazda lamp which had a very short latent period. The lamp was in a box 8 in. long, and it illuminated a horizontally placed ground glass window 2 × 3¼ in. surrounded by neutral gray paper and located some 18 in. in front of S's head. The D.C. in circuit with the lamp was varied between a maximum of 4.4 volts, 1.5 amperes and a minimum of 4.4 volts, .5 ampere. The minimum intensity of the L was fairly weak but could be clearly seen.

The Sound Stimulus.—The So was produced by an electric bell suspended by a string 22 in. directly above the S's head. Some of the ringing quality of the bell was deadened by a 6 × ½ in. piece of adhesive tape, and the bell did not continue making a sound after the current was turned off. The D.C. in circuit with the bell was varied between a maximum of 5.8 volts, .4 ampere and a minimum of 5.8 volts, .2 ampere. If the door of S's room was open, the minimum intensity of the So could just be heard by the average person some 75 ft. down the hall. The different So stimuli differed not only in intensity but also in quality and pitch.

The Shock Stimulus.—The shock was a shunt from the 60-cycle, 110-volt commercial A.C., with a resistance of 10,000 ohms in circuit with the S, and the shock was used in the 4th Tr procedure. The strength of the shock was constant for a single S, but it was set somewhere between 20 volts, .002 ampere and 36 volts, .005 ampere with different S's. The voltage was measured by a rectifier type of voltmeter, and the current was obtained by dividing the voltage across a resistance by that resistance, at the same time taking into account the current taken by the voltmeter.

The electrodes were 2 pads of felt, each ¼ in. thick and 1 in. square, and saturated with physiological salt solution. The electrodes were in contact with the palm and back of S's left hand over the 4th and 5th metacarpal bones, and they exerted a pressure of about 1 lb. on his hand, and the S's hand was free to move.

Signals, Reports, and Precautions.—The ready signal from E to S was given by a large telegraph relay on a table 4 ft. in front of S, and the relay was operated mechanically. One click meant 'Judge 2 L's' and 2 clicks 'Judge 2 So's.' The *signal from S to E* consisted of a relay in E's room in circuit with a telegraph key which S operated with his right hand. Three clicks meant "There is an error in the hook-up," and 8 to 10 clicks was a request to E to come into S's room. The *reports from S to E* were S's judgment of the intensity of the 2nd L or 2nd So compared with the intensity of the 1st L or So in each pair; and in each trial S gave a report of −3, −2, −1, +1, +2, or +3, by closing 1 of the 6 knife switches on a board in front of him, which turned on 1 of 6 light signals in my room.

I could not see the S during the experiment, and without intending to be suspicious, I took several *precautions* which enabled me to know somewhat better whether or not S were carrying out the instructions. In the attention Tr, I went into S's room from time to time to see if he were in a relaxed posture. In the verbal Tr, I kept my room door open so that I could hear him repeating the words. In the tension Tr, the S's gripping of each hand dynamometer turned on a light in my room. In the shock Tr, I occasionally put my hand in series with S's hand to see if he were taking the shock.

Apparatus Used in Giving the Signals and Stimuli.—The apparatus used in giving the ready signals and the 3 stimuli included a rotating metal drum driven by a Bodine constant speed motor. Spring bronze contact brushes, 2¼ in. long and mounted in groups of 3 or 4 on moveable handles of bakelite and wood, made contact with the drum through rectangular-shaped openings in fish paper on the drum. The circumference of the drum was 513.5 mm, and the time of 1 revolution was 16.20 sec. In the testing procedure, 2 complete trials were made with each revolution of the drum. The duration of the signals and stimuli and the intervals between them were known with a high degree of accuracy.

On the 4 *moveable handles* of bakelite and wood were mounted *contact brushes* by which it was possible (1) to give the ready signals; (2) to carry out the testing procedure in which the *2nd* of 2 L's or 2 So's was accompanied by an So or L, respectively (the 2nd stimulus together, or 'procedure T'); (3) to carry out the testing procedure in which the *1st* of 2 L's or 2 So's was accompanied by an So or L, respectively (the 2nd

stimulus alone, or 'procedure A'); and (4) to give the L and So Tr stimuli simultaneously and after irregular intervals a large number of times. In each testing procedure, a mechanical signal informed me when each of the 2 stimuli being compared by the S began and ended. In each of the 4 Tr procedures, an electric counter kept a record of the total number of repetitions of the Tr stimuli. The brushes on any 1 or on any group of the 4 handles could be readily placed in such a position that they were in contact with or not in contact with the drum.

Duration of and Intervals between the Signals and Stimuli.—The Ready Signals. Ready signals of 1 or 2 clicks of a relay were used in procedures T and A. For each click of the relay, the circuit remained closed .32 sec., and when the signal was 2 clicks, the interval between the clicks was also .32 sec. When the signal of 2 clicks was used, the interval between the end of the 2nd click and the beginning of the next ready signal was 7.15 sec. When a signal of 1 click was used, the interval between the end of the click and the beginning of the 1st stimulus in the testing procedure was 1.26 sec.; and when a signal of 2 clicks was used, the interval between the end of the 2nd click and the beginning of the 1st stimulus in the testing procedure was .63 sec.

Procedures T and A.—In each of these testing procedures, each individual stimulus continued for a period of .95 sec., and the interval between the end of the 1st stimulus and the beginning of the 2nd was always .47 sec. The interval between the end of the 2nd stimulus in one trial and the beginning of the 1st stimulus in the next trial was always 5.73 sec.

The CR Training Stimuli.—The L and So Tr stimuli were given together 5 times with each revolution of the drum, and in each repetition the 2 stimuli continued for .95 sec. In the 4th Tr procedure, the duration of the shock was also .95 sec. The irregular intervals between successive repetitions of the Tr stimuli were 1.39 sec., 3.64 sec., .82 sec., 2.03 sec., and 3.59 sec. Only 2 out of the total of 40 S's noticed that a rhythm was present practically all of the time when the Tr stimuli were being repeated.

Connecting System for Different Arrangements of Signals and Stimuli.—Besides being able to cut out any of the circuits, to vary the intensity of the 3 stimuli, and to have any set of brushes in contact or not in contact with the drum, we used a connecting system similar to a telephone switchboard to make possible prompt and orderly changes in procedure. On the far side of a board on my apparatus table were *4 sets of upright metal posts* connected with the brushes on the 4 bakelite and wooden handles of the drum apparatus. On the near side of the board were *4 wires with battery clips on their free ends*, and the clips could be readily attached to the metal posts. When the clips were attached to the proper posts, any 1 or any group of the 4 sets of circuits, (1) ready signals, (2) procedure T, (3) procedure A, and (4) the Tr procedure, would be ready to function, that is, if the appropriate sets of brushes were in contact with the drum.

To arrange for a *ready signal* of 1 click, the ready signal clip was attached to the 1st ready signal post, and when the drum rotated the signal was given mechanically. To set the apparatus for a ready signal of 2 clicks, and ready signal clip was attached to the 2nd ready signal post, and this signal was given mechanically when the drum rotated.

The free end of the *L (and also So) wire* was forked and carried 2 clips. If S was to judge 2 L's in procedure T, 1 L clip was attached to the 1st procedure T post, the 2nd L clip was attached to the 2nd procedure T post, and 1 of the So clips was attached to the 3rd procedure T post. The apparatus would then stimulate the S, first, with an L alone, and then, shortly afterwards, with an L and So together. If S was to judge 2 So's in procedure A, 1 of the L clips was attached to the 1st procedure A post, 1 of the So clips was attached to the 2nd procedure A post, and the 2nd So clip was attached

to the 3rd procedure A post. The apparatus would then stimulate the S, first, with an L and So together, and then, shortly afterwards, with an So alone. A change from 1 to another of the 4 arrangements of signals and stimuli could be made in a few sec.

To set the apparatus for giving the *L and So Tr stimuli*, 1 of the L clips was attached to the 1st Tr post, 1 of the So clips was attached to the 2nd Tr post, and when the shock Tr was used, the shock clip was attached to the 3rd Tr post.

It was possible to control the signals and stimuli in the desired manner with the apparatus described above, and there were no disturbing physical factors which had any influence on the results.

Procedure

The experiment with each S was completed in 1 sitting, and the experimental period was about 3 hrs. long.

Subjects.—The 40 S's used consisted of 12 men and 28 women, and all were students in the writer's Summer Session classes in Learning and Abnormal Psychology. About half were graduate students, each had had at least 1 previous course in psychology, but none of them understood the purpose of the experiment. At the end of the experimental period, however, about 1 out of 10 S's thought the experiment was in some way connected with the CR.

Procedure Used with an Individual Subject.—The S was seated in a comfortable Morris chair, and I showed him the objects that would be referred to in the directions. He was then given the following type-written directions, was asked to read them carefully twice, and to ask questions about matters that were not clear to him.

Procedures

Two procedures are used: (1) a Testing Procedure, and (2) a Repetition Procedure. The *testing procedure* is used in the 1st third of the experiment, the *repetition procedure* is used in the 2nd third of the experiment, and *the 2 procedures* are alternated with each other several times in the last third of the experiment.

Two different stimuli are also used: (1) a *Light* which appears in the rectangular ground glass window just in front of you, and (2) a *Sound* which comes from the electric bell directly above your head. Different intensities of these lights and of these sounds are used from time to time.

At all times when a light, a sound, or both a light and a sound are present, be sure to have your eyes directed towards the *middle* of the ground glass window.

The Testing Procedure

The testing procedure includes: (1) a *ready signal* of 1 click ('Judge 2 lights') or 2 clicks ('Judge 2 sounds') from the large telegraph relay on the table, (2) *two successive lights* (the 1st or 2nd accompanied by a sound) *or 2 successive sounds* (the 1st or 2nd accompanied by a light), and (3) *your report* by means of one of the 6 knife switches *on the intensity of the 2nd stimulus* compared with the intensity of the 1st stimulus. The 1st light in different pairs of lights is always of the same intensity, but [in every pair of lights the intensity of the 2nd light is always different from the intensity of the 1st light]. The 1st sound in different pairs of sounds is also always of the same intensity, but [in every pair of sounds the intensity of the 2nd sound is always different from the intensity of the 1st sound.]

The *4 different arrangements of signals and stimuli* used in the present testing procedure are shown below. *In each trial*, 1 of these 4 arrangements of signals and stimuli is always used, but 1 arrangement complete in all details must always be used. Time

moves from left to right in each of the 4 rows representing the 4 arrangements of signals and stimuli.

ARRANGEMENT OF SIGNALS AND STIMULI

	Ready Signal	Combination of Stimuli		Report, with 1 of the 6 Knife Switches
1	—	*Light*	*Light* (Sound)	(Use −3, −2, −1, +1, +2, *or* +3)
2	—	*Light*	*Light* (Sound)	"
3	— —	*Sound*	*Sound* (Light)	"
4	— —	*Sound* (Light)	*Sound*	"

In the 1st arrangement shown above, the single click ready signal means: "Please pay close attention to the intensities of the pair of successive lights." Although an extra stimulus, in this case a sound, accompanies the 2nd light, remember that the instructions are still to "Pay close attention to the intensities of the pair of successive lights." Let the extra stimulus, in this case a sound, have whatever natural influence it may tend to have.

These same instructions also apply to each of the *underlined pairs of successive stimuli* and to each of the *extra stimuli enclosed in parentheses* in the 3 other arrangements shown above.

Returning to the 1st arrangement shown above,—If the *2nd* light is very obviously *more intense* than the *1st* or *standard* light, report '+3'; and if the *2nd* light is very obviously *less intense* than the *1st* light, report '−3.' '+3' or '−3' is the largest difference between a pair of lights or between a pair of sounds that will be used. Report '+2' or '−2' when the difference between the 2 lights or sounds in a pair of lights or sounds is moderately clear but definitely less than the value just defined as '+3' or '−3.' Report '+1' or '−1' when the difference between the 2 lights or between the 2 sounds is slight, or when there is some uncertainty as to whether your judgment should be '+' or '−.'

[Perfect judgments in a fairly long series of some 30 or 40 trials would require the use of each of the 6 knife switches approximately an equal number of times, and there is about a 1/6 chance probability that each of your judgments will be correct.] Therefore try to use all 6 of the knife switches about the same number of times in the long run, but do not vary your judgments in any systematic way. Try at least to avoid giving practically all '3' or practically all '1' judgments. It is even more important to *pass judgment on the intensity of the 2nd stimulus* in the pair, *with reference to the intensity of the 1st stimulus* in the pair, *according to the way the 2 stimuli actually appear to you.* Also, do not make any assumptions in regard to the influence of the order and position of the combinations of stimuli, because [no assumptions are justified by what is known about these matters at the present time].

In each trial, try to *keep the same posture of all parts of the body* during the 1st and 2nd stimuli in a pair; that is, whatever position you may be in during the 1st stimulus in a pair, try to remain in this same position while the 2nd stimulus is present.

The Repetition Procedure

In this repetition procedure, there are no ready signals, and you do not make any reports with the knife switches on the intensity of any stimuli. The *Light* and *Sound*

stimuli come on at irregular intervals, but always together, and only together. Pay close attention to both Light and Sound at the same time when these 2 stimuli are present. Look at and actually see the Light. Listen to and actually hear the Sound. *Keep your eyes directed towards the middle of the ground glass window at all times when the Light and Sound are present.* (In this repetition procedure, some additional verbal instructions will be given each subject.)

Signals with the Telegraph Key

Occasional errors may occur in making the large number of electric connections necessary for the different procedures, arrangements, and combinations of stimuli; and when there is an error, the prompt use of these 2 telegraph key signals by you may save a considerable amount of time.

X. Whenever there is *any kind of error in the hook-up*, in the *ready signals*, or in the *combinations of light and sound stimuli*, do *not* report anything with any 1 of the 6 knife switches, but, instead, *press the telegraph key 2 or 3 times* (– – –). That is, if any kind of error occurs, be sure to rule out the trial and indicate the fact immediately by pressing the telegraph key 2 or 3 times.

Y. If the telegraph key signal (X) above is not sufficient, and if there is something which you believe you should say to me, and therefore *wish me to come into your room*, just stop functioning as a subject, and *press the telegraph key 8 or 10 times* (– – – – – – – – – –).

Several details of the procedure were generally not clear to the S, and after he had read the typewritten directions twice, some 15 or 20 min. were generally required to answer questions, to explain some matters further, and to demonstrate some of the arrangements of signals and stimuli. The brackets in the above directions indicate the statements which are not true, and these brackets were of course not present on the S's copy. What was referred to in the S's instructions as 'The Repetition Procedure' was actually the CR Training Procedure. While some of the arrangements of signals and stimuli were being demonstrated, we determined the amount of difference between 2 L's or between 2 So's which it was necessary to use in order to obtain correct judgments of +3 or −3 from the S in practically all trials.

A Sample Record and Further Details of the Procedure.—A sample record sheet on which I recorded the results of each S, a sample record, and several further details of the procedure are shown in Table 1. In the case of this S, No. 1, Mr. C. H., the 1st L in each pair of L's was set at 45 (on the L rheostat), and a setting of 50 or 40 for the 2nd L was judged +3 or −3, respectively, on practically all trials. The 1st So in each pair of So's was set at 35 (on the So rheostat), and a setting of 45 or 25 for the 2nd So was also judged +3 or −3, respectively, on practically all trials. In the case of this S, the standard L was always 45, and the 2nd L was generally 45 also, but when the 2nd L was different from the 1st, the 2nd L was always exactly 45 ± 5. In the case of this S, the standard So was always 35, and the 2nd So was generally 35 also, but when the 2nd So was different from the 1st, the 2nd So was always exactly 35 ± 10.

The 4 columns in Table 1 show whether procedure T or A was used when each trial was made. The 'L LSo' above the 1st column shows that in each trial the S received, first, an L alone, and then, shortly afterwards, an L and So together. In the 2nd column, an L was given alone (A) in the 2nd position, etc.

In alternate rows, trials were made and the judgments were recorded from left to right, from right to left, alternately, as indicated by the arrows on the left of the table.

The '+' and '−' signs on the left indicate the direction of the changes that were made in the strength of the 2nd stimulus, in a pair of L's or in a pair of So's. The '+−'

TABLE 1

A Sample Record and Further Details of the Procedure

Subject No. 1
Name of Subject: *Mr. C.H.*
Light Stimulus = 45 ± 5 on Rheostat

Sound Stimulus = 35 ± 10 on Rheostat
Speed of Drum = 513.5 mm. in *16.20* Sec.
CR Training Procedure: *Mere Attention*

		Together (T)					Alone (A)					Together (T)					Alone (A)				
		L				LSo	SoL				L	So				SoL	LSo				So
Test Before CR Training	→ + −	+2	+1	−1	+1	+2	−1	+1	+1	−1	+2	−2	−1	+1	−1	+1	−1	−1	+1	−2	−2
	R.T. (1/5 sec.)	18	24	34	24	20	22	13	14	22	13	19	21	14	15	17	29	24	19	21	27
	← − +	−2	−1	−1	−2	+2	+2	+1	−1	+1	+1	−1	−1	+1	−2	−2	+1	−2	+1	−2	−2
	R.T. (1/5 sec.)	15	21	20	11	11	13	16	11	16	18	19	15	14	20	24	22	18	20	27	19
	→ + −	+2	−1	+1	+2	+1	+1	−1	−1	+1	−2	−2	−2	−2	−1	+1	+2	−1	−2	−1	+2
	R.T. (1/5 sec.)	16	21	22	10	16	12	17	15	16	17	19	26	22	19	11	16	24	24	13	21
	CR Training Procedure (1, 2, 3 or 4) to 300 Repetitions. Rest 1 min. every 50 except last																				
	← − +	+2	−1	−1	−2	+1	−2	+1	+2	+2	−1	−2	+2	−2	+2	+2	−1	+2	−1	+1	+2
	R.T. (1/5 sec.)	14	11	15	15	16	16	23	9	19	19	33	12	22	10	20	20	24	24	26	14
	CR Training to 400. Rest 1 min. after 1st 50																				
Test After CR Training	→ + −	+2	−2	−2	+1	−2	+2	−1	+2	+1	−2	+2	+1	−2	−2	+2	−2	+1	−2	+2	−2
	R.T. (1/5 sec.)	11	12	15	13	14	20	6	10	13	11	16	23	8	40	19	18	16	12	25	10
	CR Training to 500. Rest 1 min. after 1st 50																				
	← − +	+2	−2	+2	+2	+2	+2	+2	−2	−1	+2	−2	−2	+2	+2	−1	+2	+2	+2	−1	+2
	R.T. (1/5 sec.)	7	18	15	8	16	15	13	12	13	10	15	23	14	21	17	17	25	20	12	11

sign means that the 2nd paired stimulus was changed, first, to the +3 value ('plus suggestion'), and later, to the −3 value ('minus suggestion'). The figures to the right of 'R.T. (1/5 sec.)' give the time between the end of the 2nd paired stimulus and S's report on its intensity compared with the intensity of the 1st paired stimulus. I measured this time by hand with a stop watch.

The details of the procedure with this S, as shown in the 1st row of the table, were as follows:

1. The plus L suggestion was given: 1st L 45, 2nd L 50. S judged the 2nd L +3, and this judgment was not recorded. (None of the judgments after the plus or minus L or So suggestion was recorded.)
2. Both L's 45, S's judgment of +2 for the 2nd L recorded.
3. Both L's 45, S's judgment of +1 recorded.
4. Minus L suggestion given: 1st L 45, 2nd L 40. S's judgment of −3 not recorded.
5. Both L's 45, S's judgment of −1 recorded.
6. Both L's 45, +1 recorded.
7. Both L's 45, +2 recorded.
8. *Combination of stimuli* changed to procedure A: and So stimulus accompanied 1st L, and 2nd L was alone.
9. Plus L suggestion given as in (1) above.
10. Both L's 45, −1 and +1 recorded.
11. Minus L suggestion given as in (4) above.
12. Both L's 45, +1, −1, and +2 recorded.
13. *Arrangement of signals and stimuli* changed to procedure T, testing 2 So's.
14. Plus So suggestion given: 1st So 35, 2nd So 45.
15. Both So's 35, −2 and −1 recorded.
16. Minus So suggestion given: 1st So 35, 2nd So 25.
17. Both So's 35, +1, −1, and +1 recorded.
18. *Combination of stimuli* changed to procedure A, testing 2 So's, etc.

In the 2nd row of Table 1, the procedures used and the recording of grades were from right to left as far as the 4 arrangements of signals and stimuli were concerned, but from left to right within a single arrangement of signals and stimuli, that is, in any 1 of the 4 columns of the table. Some of the details of the procedure in the 2nd row were as follows.

19. I kept the *same arrangement of signals and stimuli* just previously used, procedure A, testing 2 So's.
20. Minus So suggestion given as in (16) above.
21. Both So's 35, +1 and −2 recorded from left to right.
22. Plus So suggestion given as in (14) above.
23. Both So's 35, +1, −2, and −2 recorded from left to right.
24. *Combination of stimuli* changed to procedure T, testing 2 So's.
25. Minus So suggestion given as in (16) above.
26. Both So's 35, −1 and −1 recorded from left to right.
27. Plus So suggestion given as in (14) above.
28. Both So's 35, +1, −2, and −2 recorded from left to right, etc.

The details of the testing procedure were exactly the same for the 1st, 3rd, and 5th rows of Table 1, and also exactly the same for the 2nd, 4th, and 6th rows of the table. All of these details of procedure were necessary to equalize the influences of the order of the combinations of stimuli, the position of the extra stimulus, fatigue,

practise, the effects of the suggestion procedure, etc. With alternate S's, the + and − signs and the direction of the arrows were reversed.

The *suggestion procedure* caused the S's to believe that at least the very large majority of the paired stimuli were of a noticeably different intensity, and it made them much more sensitive to whatever organic differences there may have been in the effects of the 1st and 2nd stimuli in each pair. At the end of the whole experiment, the S's could hardly believe that the physical intensities of the paired stimuli were exactly the same in all cases where their judgments were recorded.

The Four CR Training Procedures.—After the test before Tr had been made and after the 1st 3 rows of grades in Table 1 had been recorded, what was referred to as the 'Repetition Procedure' in the instructions to the S was carefully explained. One of the 4 Tr's was then used until there had been 300 joint repetitions of the L and So (Tr) stimuli. The 1st test after Tr was then made, the judgments were recorded in the 4th row of Table 1, and the testing procedure was carried out exactly as in the 2nd row of the table. The Tr was then continued until the total number of repetitions of the L and So stimuli since the beginning of the experiment was 400. The procedure in the 5th row was exactly the same as in the 1st and 3rd rows, and the procedure in the 6th row was exactly the same as in the 2nd and 4th rows.

Each of the 4 Tr's was used with 10 S's, and each S was used in only 1 Tr. All of the Tr's were alike in that, with each repetition of the L and So stimuli, the S's (A) looked at the middle of the ground glass window, (B) tried to see the L and hear the So and (C) tried to pay attention to both stimuli simultaneously. The respects in which the 4 Tr's differed from each other are described below.

1. Mere Attention CR Training Procedure ('attention Tr').—S was seated in a Morris chair, and was asked to relax all parts of his body as much as possible except for the 2 sensory processes and the process of attention. He was asked to sit in a slouched and undignified posture, and to regard this (so-called) repetition procedure as a very good opportunity for resting.

2. Attention and Verbal Process CR Training Procedure ('verbal Tr').—S was seated in the Morris chair but nothing was said to him about relaxing and resting. He repeated the words 'Light, Sound, Light, Sound' audibly, rapidly, and clearly while the L and So Tr stimuli were present but only while they were present. He was asked to speak the words in such a way that another person in the room would have no difficulty in understanding what he was saying. The S's just had time to speak each of the 2 words 3 or 4 times before the L and So ceased. Alternate S's spoke the words in the order 'Sound, Light, Sound, Light.'

3. Attention and Muscular Tension CR Training Procedure ('tension Tr'). S was standing, and nothing was said to him about relaxing and resting. The L, knife switches, etc. were in a convenient position in front of him. While the L and So were present but only while they were present, S gripped a hand dynamometer in each hand with a minimum pressure of some 15 lbs. The minimum pressure required was set at different points for different S's, and the dynamometers were held in any desired position.

4. Attention and Electric Shock CR Training Procedure ('shock Tr'). S was seated in the Morris chair but nothing was said to him about relaxing and resting. When the experiment began, several trials had been made to determine (A) the minimum electric shock which S could feel, and (B) the strongest shock which he would take. The strength of the shock used in this Tr was about 2/3 of the distance from (A) to (B). We used the strongest shock that would apparently be consistent with a moderate amount of good humor while the shock was being repeated 500 times.

Results

A general summary of the results of the experiment is given in Table 2. The scores for the test before Tr and for

TABLE 2
Summary of the Results

Tests and CR Training Procedures			Test Before CR Training Procedure	Test after CR Training Procedure			
				1. Mere Attention	2. Attention and Verbal Process	3. Attention and Muscular Tension	4. Attention and Electric Shock
No. of S's			40	10	10	10	10
No. of Measures			1200	300	300	300	300
Judgment of the Intensity of the Second Stimulus in Each Pair	Av.	T	+.30	+.16	+.08	−.05	+.37
		A	+.16	+.10	+.24	+.14	+.44
		T−A	+.14	+.06	−.16	−.19	−.07
	A.D.	T	1.33	1.42	1.26	1.36	1.41
		A	1.33	1.34	1.22	1.36	1.34
		T−A	0	+.08	+.04	0	+.07
Reaction Time (Sec.) of the Judgments	Av.	T	2.19	2.11	1.93	1.83	1.94
		A	2.10	2.00	1.81	1.80	1.86
		T−A	+.09	+.11	+.12	+.03	+.08
	A.D.	T	.84	1.02	.75	.69	.87
		A	.79	.89	.68	.70	.78
		T−A	+.05	+.13	+.07	−.01	+.09

the test after the 4 Tr's are shown in the last 5 columns. The figures in the table include the Av. and A.D. of the judgments and the Av. and A.D. of the reaction times of the judgments.

Method of Calculating the Results.—The method of calculating the combined results of different S's may be illustrated by referring again to Table 1. The judgments were grouped into 4 distributions: (1) test before Tr, procedure T, (2) test before Tr, procedure A, (3) test after Tr, procedure T, and (4) test after Tr, procedure A. The Av.'s and A.D.'s of dis-

tributions (1) and (2) above are shown under test before Tr in the upper half of Table 2. Distributions (3) and (4) above were each divided into 4 further distributions corresponding to the 4 Tr's, and the Av.'s and A.D.'s of these distributions are shown in the upper half and in the last 4 columns of the table.

The same general method was used in calculating the Av. and A.D. results for the reaction times of the judgments, and these results are shown in the lower half of Table 2.

The influence of L on So responses and of So on L responses tended in the same direction, and most of our differences between these 2 sets of results are not reliable. We have therefore combined these results for judgments and also for reaction times, and have thereby increased the reliability of the measures. The combined results for the influence of L on So and of So on L also give the desired logical meaning in the present CR experiment.

Summary of the Results.—The Av. judgment in procedure T was, for the test before Tr +.30, for the test after attention Tr +.16, for the test after verbal Tr +.08, for the test after tension Tr −.05, and for the test after shock Tr +.37. For procedure A, the corresponding Av. judgments were +.16, +.10, +.24, +.14, and +.44, respectively.

The Av. reaction time in procedure T was, for test before Tr 2.19, for test after attention Tr 2.11, for test after verbal Tr 1.93, for test after tension Tr 1.83, and for test after shock Tr 1.94. For procedure A, the corresponding Av. reaction times were 2.10, 2.00, 1.81, 1.80, and 1.86, respectively.

In Table 2, each of the scores for the test before Tr was based on 1200 trials of 40 S's, and each of the scores for the test after each of the 4 Tr's was based on 300 trials of 10 S's. The S's gave judgments of −2, −1, +1, and +2, but there were no judgments of 0; and the distributions of reaction times were badly skewed and bimodal. For what it may be worth, in the test before Tr, the $P.E._{Av.}$, by the usual formula, is .03 for judgments, and .02 for reaction times. However, since the distributions are not even approximately normal, the ordinary formula does not give an accurate indication of the reliability of our measures.

T−A Results.—A number of factors influenced the sizes of the Av.'s and A.D.'s in Table 2, and the only accurate measure of the influence of the extra stimuli on the intensity of the sensory responses being judged is the algebraic difference between the results obtained in procedures T and A. In Table 2, test before Tr, the Av. judgment score was, for procedure T +.30, for procedure A +.16, and for T−A +.14. These values for T−A are the principal results of our experiment, and they have been brought together for convenience in Table 3.

TABLE 3

THE INFLUENCE OF THE EXTRA STIMULUS ON THE INTENSITY OF THE SENSORY RESPONSE BEING JUDGED (T−A RESULTS)

Tests and CR Training Procedures		Test Before CR Training Procedure	Test after CR Training Procedure			
			1. Mere Attention	2. Attention and Verbal Process	3. Attention and Muscular Tension	4. Attention and Electric Shock
No. of Measures		1200	300	300	300	300
Judgment of the Intensity of the 2nd Stimulus in each Pair	Av.....	+.14	+.06	−.16	−.19	−.07
	A.D.....	0	+.08	+.04	0	+.07
Reaction Time (Sec.) of the Judgments	Av.....	+.09	+.11	+.12	+.03	+.08
	A.D.....	+.05	+.13	+.07	−.01	+.09

This table shows that before Tr the extra stimulus reënforced the intensity of the sensory response being judged +.14, that after attention Tr the extra stimulus still reënforced the intensity of the sensory response being judged +.06, but that after the 3 other Tr's, and especially after the verbal and the tension Tr's, the influence of the extra stimulus was definitely to inhibit the intensity of the sensory response being judged.

In the test before Tr, the A.D. of the judgments was the same for procedures T and A, and T−A was 0. The T−A value for the A.D. of the judgments was also 0 in the test after tension Tr, but the T−A value for the A.D. of the judgments was greater by +.08, +.04, and +.07 in the tests after the 3 other Tr's.

The results in Table 3 show that the Av. reaction time was somewhat longer for procedure T than for procedure A on all 5 tests, but that the difference was quite small in the test after tension Tr. The T−A values which we obtained for the A.D. of the reaction times were, in the test before Tr +.05, in the test after attention Tr +.13, in the test after verbal Tr +.07, in the test after tension Tr −.01, and in the test after shock Tr +.09.

There is no doubt but that a very large number of factors had some influence on the results given in Table 3, and if the whole experiment were carefully repeated it is probable that only the larger T−A values and differences would be obtained except by chance.

Discussion of the Results

There are no previous studies in which the present procedure was used in investigating the problem of sensory conditioning, and there are few results with which to compare those that we have given in Table 3. The T−A Av. judgment value of +.14 in the test before Tr, however, is in harmony with the finding of Hartmann and others that a stimulus affecting 1 sense tends to increase the intensity of other simultaneous sensory processes.

The Inhibiting Influence of CR Training When the Training is Accompanied by an Overt Motor Act.—After the experiment had been going on for ½ or 1 hr., the S's were much less *distracted* by the extra stimulus, they could follow the directions better, and could pay closer attention to the 2 sensory responses being compared. *Sensory adaptation* was doubtless a factor in accounting for the Av. judgment value of +.06 in the test after attention Tr. Sensory adaptation would tend to reduce the Av. test before Tr score of +.14 in the direction of 0, but it would not reduce it to 0, and sensory adaptation alone could not explain the Av. judgment scores of −.16 and −.19 obtained in the tests after verbal Tr and after tension Tr, respectively.

In the tests after Tr, the Av. judgment value of +.06 was obtained after the S had done nothing but pay attention to

the L and So Tr stimuli, and the 3 other Av. judgment values of −.16, −.19, and −.07 were obtained after the S had done something more than merely pay attention to the L and So Tr stimuli. When the S performed an overt act in the verbal and tension Tr's, the tests after Tr gave the lowest negative values of −.16 and −.19, respectively. Just why 1 stimulus should have a natural reënforcing influence on the intensity of another sensory response, but have an inhibiting influence after the 2 sensory responses have been repeatedly accompanied by an overt motor act, is a result for which we have no plausible explanation.

The Use of Different Statistical Measures in CR Experiments.—In a number of experiments on the CR, 2 distributions of measures have been obtained, for (A) the test before CR training, and (B) the test after CR training. A value for the central tendency and a value for the variability have generally been computed for each distribution of measures. The CR training procedure may have an influence on the variability of the measures as well as on the central tendency of the measures, and the logic of the situation requires that the reviewer of experimental literature on the CR have some regard for both the central tendency and the variability of the measures. In reviewing my first experiment on the conditioned eyelid reaction (**2**), a few writers have discussed the central tendencies at some length, but for some unknown reason have paid no attention to the differences in variability in the tests given before and after CR training. In the present experiment I am again submitting results in the form of statistical measures of both central tendency and variability.

The 3rd row from the bottom in Table 3 shows that in the test before Tr, the A.D. of the judgments was the same in procedures T and A. The T−A values for the A.D. of the judgments were highest, +.08 and +.07, in the tests after attention and after shock Tr's, respectively, where the S did not perform an overt motor act in the Tr; and the T−A values for the A.D. of the judgments were lowest, +.04 and 0, in the tests after verbal and after tension Tr's, respectively, where the S did perform an overt motor act in the Tr.

The 2nd row from the bottom in Table 3 shows that in the test before Tr, the Av. reaction time was .09 sec. greater in procedure T than in procedure A, and somewhat similar values for T−A were obtained in the tests after 3 of the Tr's. In the test after tension Tr, however, the T−A value for the Av. reaction time was +.03 sec. The tension Tr seemed to change the T–A value for the Av. reaction time.

The last row in Table 3 shows that in the test before Tr, the A.D. of the reaction times was .05 sec. greater in procedure T than in procedure A, and the values for T−A were not markedly different in the test after verbal Tr and perhaps also not different in the test after shock Tr. The T−A value for the A.D. of the reaction times, however, was +.13 in the test after attention Tr, and −.01 in the test after tension Tr.

General Features of the Results.—Perhaps the most prominent feature of the results described above is (1) the *small size of the T−A values* for both the test before and the test after Tr. The conclusion that it is difficult to modify the sensory-verbal-judgment processes by training of the CR type is in harmony with the results obtained by Kelly (9) in his attempt to produce artificial chromæsthesia. (2) A second general result is that *what the S does during the Tr makes a difference in the results.* The introduction of muscular tension in an otherwise formalized CR training procedure produced the greatest influence on the results. (3) A third general result is that *the apparent influences of the CR training depend upon the particular statistical measure that is employed.* The apparent influences of the CR training differ according to whether one is using the Av. of the judgments, the A.D. of the judgments, the Av. of the reaction times of the judgments, or the A.D. of the reaction times of the judgments. Within the limits of the procedures that were used, these general results seem to be quite definitely established.

Summary

The experiment was concerned with the possibility of modifying the influence of stimuli on other simultaneous sensory responses by training of the conditioned response

type. In the control test at the beginning of the experiment, we measured the natural influence of a light on the intensity of an auditory response and the influence of a sound on the intensity of a visual response. The conditioned response training procedure consisted in evoking simultaneous visual and auditory responses a large number of times. In the last part of the experimental period, the influence of one stimulus on the intensity of the response in the other sense field was measured again.

The following four conditions were used with different groups of subjects in the conditioned response training procedure: (1) The subject merely paid attention to the light and sound as they were repeatedly present together, (2) In addition to paying attention to the light and sound, the subject repeated the words 'light' and 'sound' alternately while these stimuli were present, (3) In addition to paying attention, the subject gripped a hand dynamometer in each hand while the stimuli were present, and (4) In addition to paying attention, the subject received an electric shock while the stimuli were present. Measures were obtained of the influences of these four conditions on the learning process.

Before the conditioned response training procedure, a stimulus affecting one of the two senses used had the effect of increasing the intensity of the other simultaneous sensory response; but after the conditioned response training, a stimulus affecting one of the two senses had the effect of decreasing the intensity of the other simultaneous sensory response. The inhibiting influence of one sensory process on the other simultaneous sensory response was greatest after the subject had performed an overt motor act in the conditioned response training procedure. Under the conditions of the experiment, it appeared that only a slight modification could be produced in the sensory-verbal-judgment processes. The influence of conditioned response training depends upon what the subject does and what conditions prevail during the conditioned response training, and upon the particular statistical measures and indicators of conditioning that are employed. The values which we obtained for both the central

tendencies and the variabilities of inter-sensory effects before and after conditioned response training may be interpreted as favoring the general view that learning cannot be thought of as being dependent upon organic processes located exclusively in the central nervous system.

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THE EFFECT OF CIGARETTE SMOKING ON SIMPLE AND CHOICE REACTION TIME TO COLORED LIGHTS

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This study attempts to determine the effect of the smoking of one cigarette on simple reaction time to a red light and on choice reaction time to a red and a blue light. It differs from some of the previous laboratory studies on smoking in that no attempt was made to eliminate or control such factors as suggestion, anticipation or other factors that are not eliminated or controlled in everyday smoking. Rather, an effort was made to combine the practical situation of a motorist's reaction to a red stop signal, or his choice between two colored signals, and the controls of a laboratory experiment.

Most of the earlier studies consisted of attempts to find the correlation between cigarette smoking and scholarship. A number of these statistical studies were summarized by O'Shea (1). Several laboratory experiments dealing with the physiological and psychological effects of smoking were reported prior to 1921, but their results were rather inconclusive. The more important of such studies were summarized by Hull (2).

The first well controlled experiment, in which the effect of smoking on mental and neuro-muscular functions was measured, was performed by Hull (2). He developed a clever method of administering a control dose. This control was desirable for Hull's purpose, that of discovering the effect of smoking uncomplicated by extraneous factors. In real life, of course, an individual knows whether he is smoking or not, so the extraneous factors that were eliminated by Hull are often effective. Likewise it would be difficult, if not impossible, to use his method with a cigarette or a cigar. The twelve functions studied by Hull are significant, but they do not include some of the practical activities actually performed

by people, activities that may or may not be seriously affected by smoking. Of the psychological processes studied only addition revealed a reliable effect, a favorable effect as far as habitual smokers were concerned.

In more recent studies attempts have been made to determine the effect of smoking on psycho-physical functions (Fisher) (**3**), on the efficiency of the heart (Henderson, Haggard and Dolley), (**4**), on the parotid secretion and on steadiness (Winsor; Winsor and Richards) (**5**, **6**, **7**, **8**). Winsor found (**5**) that smoking is followed by inhibition of parotid secretion in the case of the non-smoker, and by excitation of secretion in the case of the smoker. Winsor and Richards found (**6**) that when most of the smoke from one cigarette was inhaled deeply by unhabituated subjects on successive days, definite changes in both motor and secretory activity occurred. Within twenty to thirty days about five percent tolerance in the extent and duration of unsteadiness was achieved. In the same time secretory activity changed from definite inhibition to at least the normal rate. Winsor and Richards required their subjects to inhale deeply each puff of the smoke. This is desirable in standardizing the dose, but, of course, it does not adhere to ordinary smoking practices of everyday life.

Method

The chronoscope used in this experiment was constructed in the psychological laboratory of DePauw University on the principle of the Metfessel psychodometer. It measures reaction time in one-one hundred-twentieths of a second, the alternations of a sixty-cycle electric current.

Eleven smokers and ten non-smokers were used as subjects. All subjects were college students. Six of the smokers were men and five were women; six of the non-smokers were men and four were women. No sex differences were found, so the results of men and women have been combined. The smoking subjects were divided into two groups according to the number of cigarettes they habitually smoke daily. Five subjects (two men and three women) smoke from one to ten cigarettes daily. Six subjects (four men and two women) smoke from eleven to twenty cigarettes daily.

Each subject was given one practice session, two control sessions and two experimental sessions of slightly over one hour each. No smoking was done in the practice session, but otherwise it was similar to the experimental sessions. It habituated the subjects to the apparatus and to the methods of the experiment and it greatly reduced the initial irregularity of their reaction times. The results in the practice sessions were recorded, but are not included in this paper. All four regular sessions were identical except that smoking preceded the two experimental sessions and did not precede the

two control sessions. The order of the sessions was as follows: smoking, no smoking, no smoking, smoking. The subjects appeared in the laboratory at the same time each day; some subjects came in the forenoon and some in the afternoon. No subject came within an hour and a half after eating or within an hour after smoking. No information was given the subjects concerning the purpose of the experiment, or concerning their own records. An attempt was made to have the activity as natural as possible, while at the same time as many laboratory controls as possible were retained.

Preceding each of the two experimental sessions each subject smoked one cigarette. The same brand—one of the three most widely sold—was used by all subjects. Each subject was instructed to take a puff every fifteen seconds for four minutes, making a total of seventeen puffs. No instructions were given concerning inhaling; the subjects were allowed to follow their usual practise. Hull instructed his subjects not to inhale and Winsor and Richards required their subjects to inhale deeply every puff. These instructions increase the standardization of the method, but decrease the practical significance of the results.

Immediately after smoking, or in the no smoking sessions at the beginning of the experiment, ten trials were taken measuring the subject's simple reaction time to a red light and ten trials measuring his choice reaction time to a red and a blue light. The same twenty trials were repeated five minutes after the smoking (or after the beginning of the control session), fifteen minutes, thirty minutes, and one hour afterward. With half of the subjects the simple reaction trials were given first; with the other half the choice reaction trials were given first. In the case of a particular subject, the simple reaction trials or the choice reaction trials were always given first.

A ready signal was given before each presentation of the stimulus. The interval between ready signal and stimulus presentation was varied irregularly from one-half to five seconds. In the simple reaction time experiment the subject was seated with the stimulus light in front of him and with his right forefinger resting on a key. The red bulb was behind a three-inch aperture covered with white tissue paper. The subject was instructed to press his key as rapidly as possible when he saw the red light in the aperture. In the choice reaction time experiment the subject's right forefinger was resting on one key and his left forefinger was resting on another key. A red and a blue bulb of approximately equal brightness were behind the three-inch aperture covered with white paper. The subject was instructed to press the right hand key when he saw a red light in the aperture and to press the left hand key when he saw a blue light. The same order of presentation of the red and blue lights was used for all subjects; the order was different for each of the five series of trials, so the subject could not memorize the order. The subjects' keys, when pressed, stopped the impulse counter and lighted one of two bulbs on the experimenter's instrument board. Ten correct trials were taken each time; that is, the experimenter recorded each error of choice, but did not count it as a trial. An opaque screen was placed between the subject and the experimenter.

Results

The mean reaction times (expressed in milliseconds) for each of the non-smoking subjects are given in Table I. Each of the reaction times in the table is the mean of the 20 trials at the particular period in the two experimental or in the two con-

TABLE I

MEAN REACTION TIMES (MILLISECONDS) OF NON-SMOKERS

Subject	Condition	Simple Reaction to Red Light					Choice Reaction: Red and Blue Light				
		Imm.	5 min.	15 min.	30 min.	60 min.	Imm.	5 min.	15 min.	30 min.	60 min.
J.J.	No smok.	186	185	184	197	206	429	426	430	406	441
	Smoking	230	213	204	191	192	450	446	437	441	423
	Differ.	+44	+28	+20	− 6	−18	+21	+20	+ 7	+35	−18
R.M.	No smok.	203	217	202	217	245	438	451	444	428	442
	Smoking	239	235	239	229	190	441	448	456	411	421
	Differ.	+36	+18	+37	+12	−55	+ 3	− 3	+12	−17	−21
S.T.	No smok.	185	168	161	161	152	407	394	408	440	390
	Smoking	211	182	161	196	198	444	418	457	402	427
	Differ.	+26	+14	000	+35	+46	+37	+24	+49	−38	+37
J.W.	No smok.	147	139	169	165	199	396	390	418	417	385
	Smoking	173	171	168	186	157	371	362	373	377	382
	Differ.	+26	+32	− 1	+21	−42	−25	−28	−45	−40	− 3
G.G.	No smok.	133	152	129	142	127	324	420	401	368	376
	Smoking	153	150	140	132	127	332	362	404	357	392
	Differ.	+20	− 2	+11	−10	000	+ 8	−58	+ 3	−11	+16
B.K.	No smok.	181	185	172	182	161	365	352	367	397	373
	Smoking	197	202	178	174	183	393	377	373	387	367
	Differ.	+16	+17	+ 6	− 8	+22	+28	+25	+ 6	−10	− 6
L.B.	No smok.	192	211	186	194	186	400	370	390	363	379
	Smoking	202	244	190	190	160	414	394	395	369	392
	Differ.	+10	+33	+ 4	− 4	−26	+14	+24	+ 5	+ 6	+13
R.W.	No smok.	184	185	187	203	218	431	427	435	422	448
	Smoking	194	220	183	200	196	394	432	443	446	408
	Differ.	+10	+35	− 4	− 3	−22	−37	+ 5	+ 8	+24	−40
E.M.	No smok.	223	210	177	192	250	418	418	431	437	412
	Smoking	229	221	200	209	197	419	437	435	426	450
	Differ.	+ 6	+11	+23	+17	−53	+ 1	+18	+ 4	−11	+38
L.M.	No smok.	182	221	172	147	157	350	341	309	324	312
	Smoking	166	167	179	157	182	348	399	377	387	355
	Differ.	−16	−54	+ 7	+10	+25	− 2	+58	+68	+63	+43

trol sessions. The difference between the reaction time in the control session and in the corresponding period of the experimental session is preceded by a plus sign, if the reaction time was larger in the experimental session; it is preceded by a minus sign, if the reaction time was smaller in the experimental session. The mean reaction times of the moderate smokers, that is, those habitually smoking from one to ten cigarettes

daily, are given in Table II. The mean reaction times of the heavy smokers, those smoking from eleven to twenty cigarettes daily, are given in Table III.

TABLE II

MEAN REACTION TIMES (MILLISECONDS) OF MODERATE[1] SMOKERS

Subject	Condition	Simple Reaction to Red Light					Choice Reaction: Red and Blue Light				
		Imm.	5 min.	15 min.	30 min.	60 min.	Imm.	5 min.	15 min.	30 min.	60 min.
V.F.	No smok.	166	176	172	161	155	437	407	390	397	422
	Smoking	177	170	169	158	172	404	369	381	390	379
	Differ.	+11	− 6	− 3	− 3	+17	−33	−38	− 9	− 7	−43
M.S.	No smok.	304	295	305	277	272	362	390	402	395	383
	Smoking	312	314	307	296	271	390	414	401	384	377
	Differ.	+ 8	+19	+ 2	+19	− 1	+28	+24	− 1	−11	− 6
B.M.	No smok.	141	145	160	148	173	377	339	367	364	329
	Smoking	139	146	136	132	137	298	307	330	342	345
	Differ.	− 2	+ 1	−24	−16	−36	−79	−32	−37	−22	+16
A.A.	No smok.	203	163	174	161	178	366	394	403	402	382
	Smoking	200	196	182	184	189	387	346	392	402	381
	Differ.	− 3	+33	+ 8	+23	+11	+21	−48	−11	000	− 1
E.E.	No smok.	173	186	172	182	162	370	362	396	406	417
	Smoking	160	154	157	168	152	385	401	410	407	386
	Differ.	−13	−32	−15	−14	−10	+15	+39	+16	+ 1	−31

The most obvious feature of the tabulated results is the large amount of individual differences revealed for the different subjects in all three groups. Some subjects in each of the three groups were apparently slowed down by smoking and some in each group were apparently speeded up. Nor is any regularity observable as to the effect of one cigarette on reaction time at any particular time after smoking. In the case of some subjects the greatest difference between the control and experimental sessions was immediately after smoking; in the case of others it was five minutes after smoking; with others it was fifteen minutes, thirty minutes, or one hour later. Not a single subject was speeded up, and not a single subject was slowed down, by smoking for all five periods at which the simple reaction time to red light was measured. In the choice reaction to red and blue lights only Subject L.B. was

[1] Habitually smoke from one to ten cigarettes daily.

TABLE III

MEAN REACTION TIMES (MILLISECONDS) OF HEAVY[2] SMOKERS

Subject	Condition	Simple Reaction to Red Light					Choice Reaction: Red and Blue Light				
		Imm.	5 min.	15 min.	30 min.	60 min.	Imm.	5 min.	15 min.	30 min.	60 min.
M.W.	No smok.	187	210	185	178	200	387	407	392	417	421
	Smoking	236	237	214	201	198	405	399	427	412	398
	Differ.	+49	+27	+29	+23	− 2	+18	− 8	+35	− 5	−23
K.W.	No smok.	165	178	178	165	187	362	382	344	309	310
	Smoking	198	191	211	201	161	297	309	384	299	340
	Differ.	+33	+13	+33	+36	−26	−65	−73	+40	−10	+30
M.B.	No smok.	228	234	212	219	202	407	396	387	429	383
	Smoking	217	205	232	235	212	356	388	398	397	389
	Differ.	−11	−29	+20	+16	+10	−51	− 8	+11	−32	+ 6
J.M.	No smok.	194	209	191	172	177	382	396	387	387	400
	Smoking	169	175	161	185	163	376	352	367	350	377
	Differ.	−30	−34	−30	+ 7	−14	− 6	−44	−20	−37	−23
A.B.	No smok.	229	188	196	172	185	382	365	393	420	374
	Smoking	186	208	234	229	218	387	405	391	415	393
	Differ.	−43	+20	+38	+57	+33	+ 5	+40	− 2	− 5	+19
F.H.	No smok.	254	244	224	214	202	362	352	392	387	354
	Smoking	198	214	206	207	228	384	369	355	337	371
	Differ.	−56	−30	−18	− 7	+26	+22	+17	−37	−50	+17

slower at all five periods, and only Subjects V.F. and J.M. were faster at all five periods.

Further evidence that little reliable difference as a result of smoking can be expected is the fact that the five mean reaction times for each subject in the control sessions are so irregular. Some subjects reacted more slowly, and some more rapidly, as the experiment progressed, even though they had not smoked. This irregularity renders unreliable most of the differences shown in the tables. It also casts considerable doubt on the reliability of Hull's procedure of taking as normal for the day one series of each of the functions measured. Averaging the mean reaction times for all five periods of the two control sessions probably gives a more reliable 'normal.'

No reliable difference is found between the number of errors in the choice reaction to red and blue lights made in the control sessions and in the experimental sessions. The mean

[2] Habitually smoke from eleven to twenty cigarettes daily.

numbers of errors made by each of the three groups of subjects and by the eleven smokers as a whole are shown in Table IV. There was such a wide variation in the number of errors of

TABLE IV

MEAN NUMBER OF ERRORS PER SUBJECT IN CHOICE REACTION TO RED AND BLUE LIGHTS

Condition	Non-smokers	Moderate Smokers	Heavy Smokers	All Smokers
No smoking	5.6	3.6	6.7	5.3
Smoking	4.1	9.4	7.2	8.2
Difference	−1.5	+5.8	+0.5	+2.9
$\sigma_{diff.}$	3.12	3.91	1.72	2.08

TABLE V

EFFECT OF SMOKING ON SIMPLE REACTION TIMES (MILLISECONDS) TO RED LIGHT

Group of Subjects		No Smoking Sessions [3]	Smoking Sessions [4]				
			Immed.	5 min.	15 min.	30 min.	60 min.
Non-Smokers	Mean	186	199	200	184	190	178
	σ_m	1.64	3.61	3.83	3.35	3.55	3.75
	Difference [5]		+13	+14	−2	+4	−8
	$\sigma_{diff.}$		3.97	4.17	3.73	3.91	4.09
Moderate Smokers	Mean	195	197	196	190	187	184
	σ_m	2.93	7.02	7.46	6.98	6.99	5.46
	Difference		+2	+1	−5	−8	−11
	$\sigma_{diff.}$		7.61	8.01	7.57	7.58	6.20
Heavy Smokers	Mean	203	201	205	209	209	197
	σ_m	1.82	4.43	4.40	4.99	4.77	4.73
	Difference		−2	+2	+6	+6	−6
	$\sigma_{diff.}$		4.79	4.76	5.31	5.11	5.07
All Smokers	Mean	200	199	200	200	198	190
	σ_m	1.67	4.07	4.38	4.37	4.15	3.69
	Difference		−1	0	0	−2	−10
	$\sigma_{diff.}$		4.40	4.69	4.68	4.47	4.05

[3] Grand mean of all the reaction times recorded for all subjects (100 reaction times for each subject) in each group for both control sessions.

[4] Mean of all the reaction times recorded for all subjects (20 reaction times for each subject at each of the five periods) in each group for both experimental sessions.

[5] Difference between the mean reaction time at each period in the experimental sessions and the grand mean for all reaction times in the control sessions; an increase in the reaction time for the experimental sessions over that for the control sessions is indicated by a plus sign, a decrease by a minus sign.

choice made by the different subjects that the means are of little significance; several subjects made no errors at all, in either the control or experimental sessions. The only difference that approaches reliability is that of the moderate smokers: according to the standard error of the difference there are 93 chances in 100 that the moderate smokers would make on the average more errors within one hour after smoking one cigarette than if they had not smoked.

Table V gives the mean simple reaction times to red light of each of the three groups of subjects and of the smokers as a whole in each of the five periods following the smoking of a cigarette. Differences are computed between the mean for each of the five periods and the grand mean for all reaction times in the control sessions. As pointed out above the latter is probably a more reliable 'normal' than the mean of a short series of trials taken the same day as the experimental session. A 'normal' reaction time is in any case largely fictitious.

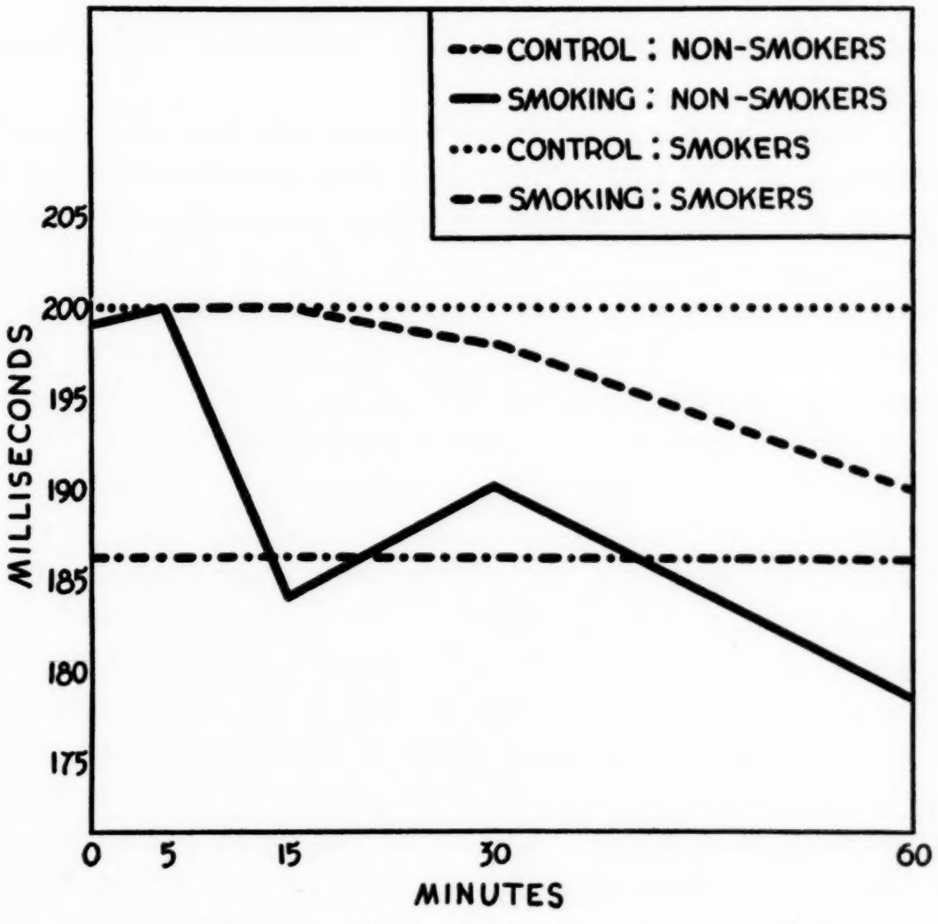

FIG. 1. Effect of smoking on simple reaction times to red light.

Curves of the mean reaction times for the non-smokers and the smokers are shown in Fig. 1.

Inspection of Table V and Fig. 1 reveals the fact that the only statistically reliable differences in reaction time that might be a result of smoking are in the case of the non-smokers. Immediately after smoking the reaction time was 13 milliseconds greater that 'normal'; five minutes after smoking the reaction time was 14 milliseconds greater than 'normal.' Each of these differences is more than three times the standard error of the difference. Fifteen minutes after smoking the non-smokers are back to 'normal' and remain there for the rest of the hour. Table I shows that immediately after smoking all the subjects except one had an increase in reaction time. After five minutes all except two had an increase. After one hour five subjects had an increase and five had a decrease. It seems safe, then, to draw the conclusion that most non-smokers would be slowed down in their reaction to red light for at least five minutes after smoking one cigarette. The amount of the effect would differ markedly for different individuals.

It seems likewise permissible to conclude that most regular smokers would be little affected in their reaction time to red light by the smoking of one cigarette, although a few might have a marked increase or decrease. Tables II and III show that four smokers were slowed down after smoking and seven were speeded up. One heavy smoker, however, was 49 milliseconds slower after smoking than in the corresponding period of the control sessions; this was a greater effect than was revealed in the case of any of the non-smokers. There seems to be a tendency for smokers to react more rapidly than 'normal' one hour after smoking; the difference is more than twice the standard error of the difference. The tendency toward a decreased reaction time seems to be slightly greater in the case of the moderate smokers than in that of the heavy smokers.

Table VI gives the mean times of choice reactions to red and blue lights of each of the three groups of subjects and of the smokers as a whole. Curves of the mean reaction times for the non-smokers and the smokers are shown in Fig. 2.

TABLE VI

EFFECT OF SMOKING ON CHOICE REACTION TIMES (MILLISECONDS) TO RED AND BLUE LIGHT

Group of Subjects		No Smoking Sessions	Smoking Sessions				
			Immed.	5 min.	15 min.	30 min.	60 min.
Non-Smokers	Mean....	403	400	407	415	400	402
	σ_m.....	2.39	5.78	5.56	6.16	5.05	4.88
	Difference		−3	+4	+12	−3	−1
	σ_{diff}.....		6.25	6.05	6.61	5.55	5.43
Moderate Smokers	Mean....	391	397	367	382	384	373
	σ_m.....	3.14	7.02	6.33	8.08	7.11	6.03
	Difference		+6	−24	−9	−7	−18
	σ_{diff}.....		7.69	7.07	8.67	7.77	6.80
Heavy Smokers	Mean....	386	368	370	387	368	380
	σ_m.....	3.03	6.96	6.68	6.20	7.35	6.76
	Difference		−18	−16	+1	−18	−6
	σ_{diff}.....		7.59	7.33	6.90	7.95	7.41
All Smokers	Mean....	389	383	369	385	376	377
	σ_m.....	2.19	5.13	4.91	4.95	5.24	4.61
	Difference		−6	−20	−4	−13	−12
	σ_{diff}.....		5.58	5.38	5.41	5.68	5.10

No reliable effect is found in the case of non-smokers, although individuals may be slowed down or speeded up. Seven non-smokers had a greater reaction time and three had a smaller reaction time immediately after smoking.

There is a fairly reliable tendency for regular smokers to react more rapidly in a choice reaction to red and blue lights for at least an hour after smoking one cigarette. Five minutes after smoking the difference is 20 milliseconds in favor of smoking; this difference is more than three times the standard error of the difference. At the five-minute period seven out of eleven smokers in Table II and III showed a decreased reaction time in the experimental sessions. Thirty minutes after and one hour after smoking the differences in favor of smoking are still more than twice the standard errors. Immediately after smoking the heavy smokers have a much greater tendency than the moderate smokers toward a reduced

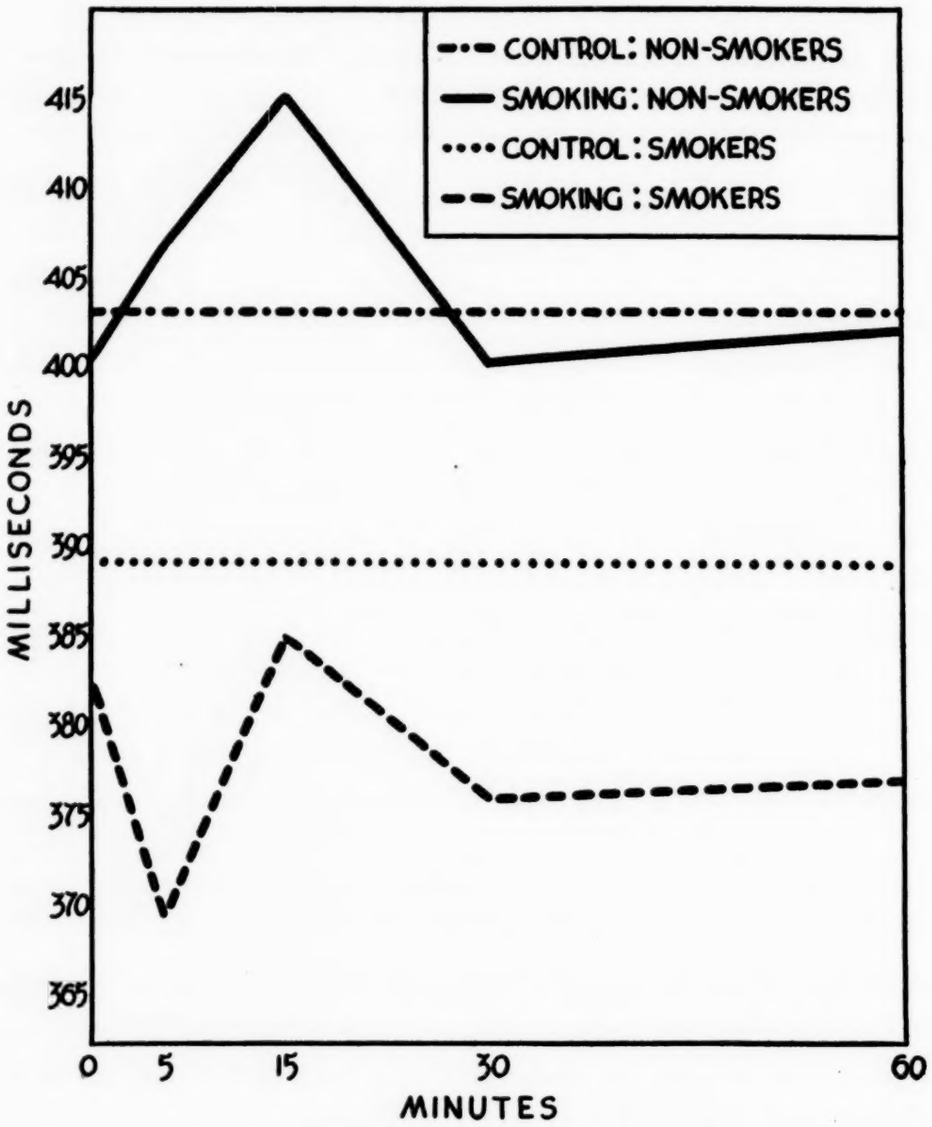

FIG. 2. Effect of smoking on choice reaction times to red and blue lights.

reaction time, while one hour afterward the moderate smokers have a greater tendency than the heavy smokers toward a reduced time.

SUMMARY

1. Individuals differ so much at different times in their simple reaction time to red light and in their choice reaction time to red and blue lights that no statistically reliable 'normal' can be taken as the basis of comparison with smoking sessions.

2. Individuals, both non-smokers and regular smokers, differ markedly in the apparent effect which the smoking of one cigarette has on their reaction times, either simple or choice, to colored light.

3. Individuals differ markedly in the length of time after smoking one cigarette at which the greatest apparent effect of the smoking occurs.

4. Smoking apparently does not significantly affect the number of errors made in choice reaction to red and blue lights.

5. Non-smokers tend to react more slowly to red light for about five minutes after smoking one cigarette; regular smokers are little affected.

6. Regular smokers tend to react more rapidly to a choice between red and blue lights for at least one hour after smoking one cigarette; non-smokers are little affected.

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AN INVESTIGATION OF THE EFFECT OF AUDITORY STIMULATION ON VISUAL SENSITIVITY

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Recent theory in psychology has stressed the concept of the 'unity of the senses.' The work of Hornbostel [1] in particular has received much attention. Hartshorne's [2] recent philosophical treatise on the psychology and philosophy of sensation is an independent attempt to unify the senses within the framework of his doctrine of the 'affective continuum.'

The most provocative work in this field has been done on a highly complex psychological level, as in comparing the respective brightnesses of color, sound, touch, etc., in which the likenesses and similarities between the sense modalities are somehow felt or sensed. Hartshorne states the problem in the following words: "In an organism, all the parts, being alike organs, display analogies to one another, are more or less kin." The degree of apprehended likeness is not always dependable. There is considerable disagreement among investigators [3] and among observers investigated, as in the case of synaesthesia, for example.[4] The phenomenon is real enough, but it is highly subjective and does not easily yield to experimental analysis. Consequently, in the present state of our knowledge this unity of the senses can only be described in a more or less literary manner as something dependent on the so-called 'higher mental processes.'

Much of the indefiniteness as to the mechanisms involved in the unification of the senses would be lessened if the condi-

[1] Hornbostel, E. M. V., Die Einheit der Sinne. *Melos*, 1925, **4**, 290–297.

[2] Hartshorne, C., *The philosophy and psychology of sensation*. University of Chicago Press, Chicago, Ill., 1934.

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tions underlying inter-relations between senses could be specifically stated, and especially if these conditions could be stated quantitatively. If the relation between the senses is essentially one of apprehending analogies or likenesses between modalities, in terms of some complex correlate such as thought or feeling tone, then probably all that we can expect to determine in the near future are the conditions under which these likenesses are most readily apprehended. Some tentative scheme of continuity between the senses may also be theoretically proposed. On the other hand, if the senses are related primarily by the physiological mechanisms ordinarily operating within the sense modality, then their inter-dependence should be observable and measured with the degree of precision obtained in sensory discrimination.

The research here reported has undertaken because certain recent investigations seem to indicate that the inter-relation between sense modalities can be measured in terms of some observable sensory factor. Kravkov [5] and Hartmann [6] measured the effects of auxiliary stimulation on the visual mechanism in terms of changes in visual acuity. These studies recall the older work of Urbantschitsch,[7] who obtained changes in color threshold as a result of indirect stimulation with sound, taste, touch, and pain. This early work was essentially qualitative in nature and so must be regarded as a preliminary survey.

By means of a telephone device, tied up with a low frequency cathode tube generator transmitting a tone of 2,100 d.v., Kravkov determined for 10 subjects the least noticeable interval between two white squares on a black background, and likewise with black squares on a white ground. His results show that using black squares on a white ground the visual acuity of nine of his subjects was increased, while for

[5] Kravkov, S. W., Changes in the visual acuity in one eye under the influence of the illumination of the other or of acoustic stimuli, *J. Exper. Psychol.*, 1934, **17**, 805–812, and other references by the same author here listed.

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white figures on a black ground an equally significant lowering of acuity took place. Kravkov offers an explanation in terms of the expansive property of white under general senory excitation. Under these conditions the white squares tend to irradiate and partially obliterate the interval between the white figures, or to enlarge the interval between the black squares. Data similar to those of Kravkov have been reported by Gotoh.[8] Hartmann's studies were in part a repetition of Kravkov's experiment under the two typical conditions of white and black background. Hartmann found slight increases in visual acuity under both conditions. With tones of 180 d.v. and 2,100 d.v. similar slight changes in acuity were found. Hartmann also worked with olfactory, taste, tactile, and pain receptors as auxiliary stimuli. In all cases visual acuity was slightly increased. An explanation of these phenomena is tentatively offered in terms of some form of diffusion from one part of the cortex to another, presumably through the medium of the so-called association fibers. Other studies of a similar nature, supporting the general idea of cortical diffusion from one sense modality to another, are those of Johnson,[9] and Mukherjee,[10] Thorne [11] reports instances of inhibition as well as facilitation of visual sensitivity through the introduction of a simultaneous stimulus consisting of a buzzer.

Thus a review of the literature in this field reveals considerable evidence for the cortical-diffusion theory of intersensory activity. The most definite result is the demonstration that diffusion may be measured in terms of visual acuity limens. Visual acuity is affected by many complex factors, but the implications derived from the above experiments are that sensitivity for vision is changed with simultaneous stimulation of another sense organ. If these implications are true

[8] Gotoh, C., Ueber die Zentrale Beeinflussung der Sehschärfe, *Zentralb. f. Ophthalmol.*, 1931, **26**, 224.

[9] Johnson, H. M., Dynamogenic influence of light on tactile discrimination. *Psychobiol.*, 1920, **2**, 351–374.

[10] Mukherjee, K. E., Duration of cutaneous sensation and improvement of its sensible discrimination by practise. *J. Exper. Psychol.*, 1933, **16**, 339–342.

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then a more direct measure of sensitivity in terms of threshold for light offers a critical check. Since the amount of evidence on this point is yet quite meagre, we consider the following negative results worth presenting.

Apparatus

The apparatus consisted of two units, (1) a spectral light source and (2) a source of sound. For the first, a Gaertner Rapid Setting Monochromator was used. An image of the exit slit was focused upon an artificial pupil. A chin rest and individual biting boards containing the subject's dental impression on beeswax were placed conveniently near the artificial pupil so that the observer could look through the pupil and maintain steady fixation. The field of observation was a patch of light defined by a diaphragm in front of a condensing lens. The diaphragm subtended a visual angle of 1° 55′. In the center of the diaphragm was mounted a small nickel-plated ball. This served as a fixation-point when illuminated by a fine pencil of rays from a flashlight bulb whose intensity was regulated through a rheostat. The voltage of the spectral light source was kept constant; change in the intensity of the stimulus was accomplished by a Wratten Neutral Tint Wedge placed in front of the exit slit. The wedge was moved by a screw to which a crank was attached for the purpose of easy adjustment. An indicator moving upon a millimeter scale showed the position of the wedge. The wedge was 10 cm long with a transmission range from 1 to 1/1,000.

Sound was obtained by means of an oscillating circuit containing an amplifying stage. The sound was transmitted to the subject's head by means of radio head-phones. In the following experiments a sound of 410 d.v. was used. The sound seemed to be quite loud but not uncomfortable. The only way of specifying the intensity available here was by means of a Dorsey Pheneloscope. One of the head-phones was placed a quarter of an inch from the diaphragm of the instrument. With this arrangement the beam reflected from the instrument registered a deflection of 3.5 inches on a screen 63 inches distant.

The Effect of Auditory Stimulation on the Absolute Threshold for Light

Three subjects, including the senior author, took part. The younger observers were majors in the department of psychology and had had considerable experience in observing visual phenomena. Thorough preliminary observations were made by the senior author to attain satisfactory conditions. All subjects devoted at least one sitting to practise in determining thresholds. In the actual experiment the procedure was as follows. The observer was dark adapted for about 15 minutes. Then he seated himself comfortably with his chin supported in such a way that his right eye was in position for the artificial pupil. The experimenter then gave a ready signal, and shortly following it sound and light were presented simultaneously. The threshold was determined by modified method of limits, the experimenter simply moving the wedge until the subject reported the threshold condition. The sound continued until the threshold was announced by the observer. Between trials the overhead lights, which were partially draped with dark cloth, were put on for a few seconds. Then a pause of several seconds was made to allow for dilatation of the pupil before resuming the observations. This procedure was followed because it promoted easy and constant fixation. It is well known that continual fixating of a point in a totally dark field having no contours is not only very fatiguing but hard on the accommodation. The eyes tend to change con-

vergence, and since accommodation tends to be correlated with convergence blurring of the observed field occurs. The displacement of convergence from the visual plane is particularly liable with monocular vision. However, if the subject is permitted to see the visual field, with its contours and background, for a few seconds before the lights are eliminated fixation is easily established and can be comfortably maintained for a time. Altogether each subject made 50 ascending and 50 descending judgments for both the normal and sound series. The judgments were divided between the sound and the no-sound series in bunches of ten; after 10 judgments with sound, 10 without were taken, etc.

For this experiment a spectral light of 506 mμ was used. The test field was observed through an artificial pupil 2.5 mm square.

Table 1 contains the total data collected in this part of the experiment. These data indicate that no significant differences between normal and sound series were present.

TABLE 1

VISUAL SENSITIVITY AT THE GENERAL THRESHOLD FOR LIGHT OF 506 Mμ UNDER AUDITORY STIMULATION

Subject	Ascending Order						Descending Order					
	Normal Series		Sound Series		Difference		Normal Series		Sound Series		Difference	
	Mean	Sigma (ave.)	Mean	Sigma (ave.)	Diff. of Means	Sigma (diff.)	Mean	Sigma (ave.)	Mean	Sigma (ave.)	Diff. of Means	Sigma (diff.)
K	16.168	.032	15.98	.043	+.188	.0536	15.478	.039	15.556	.035	−.078	.0524
H	15.41	.039	15.46	.046	−.05	.059	15.108	.031	15.12	.034	−.04	.045
L	15.476	.035	15.386	.033	+.09	.048	15.028	.028	15.028	.032	.00	—

The steps indicated are steps on an arbitrary centimeter scale. Results showing an increase in sensitivity through sound are given as positive results.

The Effect of Auditory Stimulation on the Specific Threshold for Color

For this purpose a spectral light of 710 mμ was chosen because the total or nearly total lack of the photochromatic interval at the red end of the spectrum renders easier the judgment of presence or absence of hue. Furthermore, light from the extreme red end is not affected by dark adaptation as much as are other spectral lights so that the sensitivity for the para-foveal region, at least up to 10 degrees, is very close to that of the fovea.[12, 13] Slight shifts in fixation should therefore not affect the threshold.

[12] Abney, W. and Watson, W., The threshold for different colored lights, *Phil. Trans. Roy. Soc.*, 1916, **216**, Ser. A, 91–128.

[13] Kohlrausch, A., Untersuchungen mit farbigen Schwellenprüflichtern über den Dunkeladaptationverlauf des normalem Auges, *Pflügers Arch. f. d. ges. Physiol.*, 1922, **196**, 113–122.

The artificial pupil was removed to add to the comfort of the observer, since it was believed to be unnecessary for work involving dim lights and especially with the large pupillary dilation under conditions of dark adaptation. A further simplification consisted of introducing a diffusing fine ground glass at the diaphragm in order to produce a surface of diffused light. Under these conditions the stimulus would not be easily obliterated if the eye was moved slightly as would happen if the beam were left focused on the lens of the retina.

In the former experiment a modified method of limits was used, but because of some observed inadequacies in the method, the method of constant stimuli was substituted in this experiment. With the former method it was possible for the experimenter to move the wedge slightly beyond the threshold noted by the observer. Introspections revealed that the continuous presence of sound while the threshold was approached caused some distraction, and initiated a tendency to reach a judgment as soon as possible in order to be relieved of the division of attention between two stimuli. This kind of tension was particularly true of the first readings; distraction subsided with repetition of the stimuli. It should be noted that the sound was not too loud or uncomfortable and only slightly so when prolonged. Sound and light were presented simultaneously by means of a magnetic shutter placed in the path of the beam of light entering the entrance slit of the spectrometer, and connected with the sound apparatus in such a way that the stimulus could be presented singly or in combination with the sound by moving only one switch. The stimulus was cut off when the observer gave his judgments which usually took place in about 1 second.

The previous procedure of dark adapting the eyes for 15 minutes, then snapping the light on for a few seconds while the subject obtained his fixation, then turning off the light, and several seconds later presenting the stimuli was again followed. In order to be sure that this procedure was reliable, an experiment was performed to test the stability of the limen obtained at different times. The threshold was determined for subject K during the morning hours based on 25 readings per step in the constant stimuli series. The following evening the experiment was repeated. The limens were practically identical, 20.90 and 20.92 mm.

The results presented in table 2 are based on 480 readings taken from two subjects. After five readings per step were obtained, a rest period followed, and then a series of five more readings per step were taken. Each rest period initiated a change from one experiment to the other (with or without

TABLE 2

VISUAL SENSITIVITY AT THE SPECIFIC COLOR THRESHOLD FOR A LIGHT OF 710 mμ (METHOD OF CONSTANT STIMULI)

Subject	Normal Series		Sound Series		Difference	
	Limen	P.E.	Limen	P.E.	Liminal (diff.)	P.E. (diff.)
K	19.541	.031	19.55	.033	−.009	.043
E	19.834	.041	19.85	.044	−.016	.06

sound). The limens were calculated by the curvilinear interpolation (Lc_4) method for computing constant stimuli limens developed by Newhall.[14] The P.E.'s were obtained by a formula recommended by Newhall.[15]

These results confirm those obtained in the previous experiment. Not only are the differences negative in character but in most cases they are only a fractional part of the probable error values.

The experiments here presented indicate that visual sensitivity as measured in terms of the threshold for light and color is not enhanced with simultaneous stimulation with an auxiliary sound stimulus. These results are in some measure contradictory to expectations based on recent studies on sensory interaction. They are particularly difficult to reconcile with Hartmann's explanation that there is a general cortical diffusion from one area to another. Kravkov's interpretation in terms of areal enlargement of the light patch is not definitely controverted by our data. It may be that sensory interaction is of the nature of areal irradiation rather than intensity change per unit area. The mechanisms involved may consist in the bringing of new elements into excitation rather than increasing the activity of the elements already activated. Why new elements outside of the stimulated area rather than those inside the activated area are brought into action by a secondary stimulus is not altogether clear. There is a further complication. Apparently, spatial summation in the retina is most effective when small stimuli are used, and summative effects are greater on the periphery than on the fovea. In other words the size of the stimulus may be a critical factor. Shaad [16] found that binocular brightness summation on the peripheral retina increased inversely with the size of the area. Within certain limits it is well known that area and brightness are interchangeable. The stimulus patch used in our experi-

[14] Newhall, S. M., Linear interpolation versus the constant process, *J. Exper. Psychol.*, 1931, **38**, 390–402.

[15] Newhall, S. M., An interpolation procedure for calculating thresholds, *Psychol. Rev.*, 1928, **35**, 46–66.

[16] Shaad, D. J., Binocular brightness summation in dark adaptation, *Arch. of Ophth.*, 1934, **12**, 705–708.

ments is within this range but since we worked on the rod-free area it may have been too large to show the effects of secondary stimulation. In this connection it may be well to point out that the visual acuity test is probably the most delicate test of areal changes on the retina available.

On the other hand our negative results are not altogether unexpected. Studies on binocular summation, between corresponding retinal areas, where on neurological grounds summation might well be expected, is still an undecided issue in spite of much careful experimentation.[17] Moreover, Hartmann's experiments which were in part a repetition of those of Kravkov, on the whole tend to weaken the impressive data obtained by the latter. Although Hartmann claims to have verified the facilitating effect of an auxiliary stimulus on visual acuity his limen differences are so small, that even if they were regarded as statistically reliable, it is doubtful that an explanation in terms of a central sensory effect is the most feasible one. In their magnitudes and in the nature of their sampling the data resemble the kind obtained when complex problems are studied with results which are attributable to mental set, preferences as between stimuli, etc.

Summary

The effect on visual sensitivity of simultaneous stimulation with a tone was measured. No reliable differences were obtained for both the general and specific color threshold. These results are discussed with reference to the reported observations that visual acuity is increased in the presence of a simultaneously acting auxiliary stimulus. Since the threshold for light is a direct measure of the sensitivity of the retina, the negative results obtained between sound and sight indicate either (1) that the alleged cortical diffusion is obtainable under particular conditions, not covered by these experiments, or (2) that the mechanism of diffusion is of such a nature that sensitivity for light is not primarily affected.

(Manuscript received September 27, 1935)

[17] Graham, C. H., Vision III. Some neurol correlations. In *Handbook of General experimental psychology*, pp. 867–871.

AN EXPERIMENTAL EVALUATION OF THE SIGNIFICANCE OF THREE FACTORS INVOLVED IN MOTOR PERFORMANCES FOR GENERAL MOTOR ABILITY

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Investigations of so-called motor abilities have consistently led to the conclusion that the doctrine of the generality of such abilities is not supported by experimental findings. The small degree of statistical correlation found to exist between performances by the same subjects on different motor tasks constitutes the evidence on which this conclusion is based. A correlation coefficient of + .25 may be taken as representative of these data. Specificity in motor abilities is therefore the favored explanatory principle.

The method generally employed in such investigations has not permitted the accumulation of much information concerning the relative importance of various variable factors discernible as entering into the measured tasks for the degree of relationship found. It has not been shown whether the low correlations between motor performances are a function of differences between the correlated performances in their sensory aspects, their overt motor aspects, or in their perceptual, cognitive aspects. Therefore it is not known what similarity must exist or what differences may exist between motor performances if they are to correlate highly. The method of comparing performances by the same reagents on different tasks when the determining aspects of the two tasks are allowed to operate uncontrolled gives the experimenter no information relative to an understanding of motor ability beyond the bare correlation coefficient.

In a series of experiments, with the third of which the present report is concerned, the author has attempted an experimental analysis of the problem of generality or specific-

ity in motor abilities. The first of these experiments was designed to locate several motor performances which, contrary to the general finding, would be highly intercorrelated.[1] The method employed involved the selection of motor performances apparently identical in all respects but one, the musculature to be used in operating the necessary apparatus. A serial pursuit task was constructed of such nature that it could be carried on with equal facility by either arm or leg thus permitting four performances to be observed. Duplicate instruments for presentation of stimuli and recording of responses were built and placed one at shoulder level for arm operation and one just off the floor for leg operation. The subject sat on a stool in front of these instruments and, for an arm performance, operated the upper instrument by means of a baton held in the hand. For a leg performance the subject operated the lower instrument by means of a baton strapped to his shoe. Inter-correlations between these four performances were found to range from .84 to .96. These correlations were interpreted as indicative of the high degree of generality in motor abilities to be found when many of the heretofore uncontrolled and unmeasured variables affecting the tested performances are controlled and equated. One may say that for each subject there exists to a large degree a common or general ability for these tasks which is expressed in terms of the relative rank obtained. The variable factor of overt musculature employed is apparently of minor significance in determining the relationships between the total performances.

In succeeding experiments it has been the object of the experimenter to discover what uncontrolled factor or factors might have contributed to the finding by other investigators of low inter-correlations between motor performances. The four performances developed by the first experiment have been repeated with new subjects[2] and in each such new experiment a separate variable, equated in the first or original

[1] CAMPBELL, M., The 'personal equation' in serial pursuit performances, *J. App. Psychol.*, 1934, **18**, 785–792.

[2] CAMPBELL, M., The cognitive aspects of motor performances and their bearing on general motor ability, J. EXP. PSYCHOL., 1936, **19**, 323–333.

experiment, has been permitted to operate differentially between performances. Reductions from the level of the first experiment in the size of inter-performance correlations brought about by the introduction between performances of any such variation in the experimental situation have been interpreted as measures of the importance of the particular variation in question for the finding of data favorable or unfavorable to the doctrine of general motor ability.

The experiment to be described here is the third of the series. Its purpose was to determine the importance of each of three factors which are found in the four tasks of the first or original experiment. The reduction in correlation found when these factors are made differential between performances as compared to the correlation found when they were equal between performances is taken as a measure of their importance. The three factors are; first, the side of the body, left or right, on which the overtly operating musculature is located; second, the end of the body, arm or leg, to which the overtly operating musculature is attached; and third, the visibility of the task, that is, whether both the stimuli and the reaction keys are visible to the subject or only the stimuli.

The Experiment

A new group of subjects numbering 54 were employed as reagents in this experiment. These subjects were male sophomores taken from psychology classes at Stanford University. The apparatus used in this experiment was exactly the same as that described for the original experiment.[3] Visual stimuli were employed throughout and there were duplicate reaction boards, one at shoulder height and the other at ankle height.

The method of presentation of tests was as follows. Each subject had 8 trials of 15 seconds each on each of 6 different tasks. For the first task the subject was instructed to operate the apparatus with the right arm, getting the stimuli from the upper or arm reaction board. For the second task he was to operate with the left leg, getting the stimuli from the *upper* reaction board. In this second performance the reaction was made as usual in the direction of the stimulus light whether it was up, down, to the right or left although the subject could not see the reaction board on which he was working with his baton. This situation, in which the subject could not see the reaction board on which he was working, was also a characteristic of the third, fifth, and sixth tasks. It results from the fact that the two reaction boards are set so far apart that only one can be seen at a time and the possible alternative to the subject of

[3] Campbell, M., Instrument for measuring the serial reaction-times of large muscle groups, *Amer. J. Psychol.*, 1934, **46**, 481–483.

looking back and forth between the two boards for each reaction was too time consuming to be even attempted. For the third task the subject was to operate with the right arm, getting the stimuli from the *lower* or leg reaction board. In the fourth task he was to operate with the right leg while getting the stimuli from the lower reaction board; fifth, to operate with the left arm while getting the stimuli from the *lower* reaction board; and sixth, to operate with the right leg while getting the stimuli from the *upper* reaction board.

Nine subjects began the experiment by taking 1 trial on the first performance, proceeding immediately to the second performance for 1 trial, then to the third for 1 trial, etc. The subjects, having received 1 trial on each of the 6 tasks repeated the series 7 times so that, finally, each task had been performed 8 times. Nine subjects began with the second task and went through the series ending with performance 1. Nine subjects began with the third task and went through the series ending with performance 2. Following this procedure each of the 6 tasks was done 9 times in each position in the series thus distributing equally any specific effect due to position in the series of the respective performances.

In Table I are brought together the statistical measures and relationships compiled from the scores made by the 54 subjects on the 6 respective performances. The mean scores represent the average number of reactions made in 8 trials. The reliability coefficients were obtained from the correlation of the scores of odd versus even numbered trials, this being stepped up by the Spearman-Brown formula to give the total reliability. They are shown in Table I on the diagonal running from the upper left corner to the lower right hand corner. Uncorrected correlation coefficients are placed below the reliability coefficients and, corrected for attenuation, they appear again above the diagonal. Critical ratios ($D/\sigma D$) for differences between means appear under the corresponding correlation coefficients. Under each of the 21 correlation coefficients in Table I is placed a set of 3 letters which indicates the correspondence between the 2 performances represented in the correlation in the 3 factors investigated. Each of the 6 performances is represented in Table I by a set of 3 letters indicating the combination of the 3 factors involved in that performance.

It will be observed that the letter symbols in Table I occur in sets of 3, which number corresponds to the number of factors mentioned in the title of this article. The meaning of these letters depends not only on the letter itself but also on its position in the set. In the first position the letter *R*

TABLE I

EXPERIMENT 3

R = Right
A = Arm
L = Left (when in first position)
L = Leg (when in second position)
S = Same
D = Different
B = *Both* stimuli and keys seen
O = *Only* stimuli seen

	RAB	RAO	LAO	RLB	RLO	LLO
Means	32.6	31.2	30.7	30.3	29.6	28.6
S. D.	2.6	2.3	2.2	2.7	2.7	2.6
RAB	.97±.01 SSS	.92±.01 SSD 10.7	.90±.02 DSD 12.7	.82±.03 SDS 10.9	.77±.03 SDD 12.5	.72±.04 DDD 15.4
RAO	.89±.02	.98±.01 SSS	.92±.01 DSS 4.1	.82±.03 SDD 4.3	.75±.03 SDS 6.6	.72±.04 DDS 10.4
LAO	.86±.02	.88±.02	.95±.01 SSS	.85±.03 DDD 2.1	.79±.03 DDS 5.0	.79±.03 SDS 10.0
RLB	.80±.03	.80±.03	.82±.03	.97±.01 SSS	.95±.01 SSD 6.4	.87±.02 DSD 9.4
RLO	.74±.04	.73±.04	.76±.03	.91±.01	.96±.01 SSS	.92±.01 DSS 7.1
LLO	.69±.04	.70±.04	.75±.03	.84±.03	.88±.02	.96±.01 SSS

Correlations Grouped According to the Combination of the 3 Factors and Correspondence in Combinations

Types	*N*	Median *r*
SSS	6	.965
SSD	2	.935
DSS	2	.92
DSD	2	.885
SDD	2	.795
SDS	3	.79
DDD	2	.785
DDS	2	.755

	Median *r*
Same *vs.* opposite sides	
1. SSS, SSD, SDD, SDS	.87
2. DSS, DSD, DDD, DDS	.86
Same *vs.* opposite ends	
1. SSS, SSD, DSS, DSD	.92
2. SDS, SDD, DDS, DDD	.78
Same *vs.* opposite visibility	
1. SSS, DSS, SDS, DDS	.87
2. SSD, DSD, SDD, DDD	.87

means *right*, that is, a performance of a limb on the right side of the body. The letter *L* means *left*, that is, a performance of a limb on the left side of the body. The letters *S* or *D* in the first position mean that, for the indicated correlation, the two limbs correlated were on the *same* or *different sides* of the body. In the second position the letter *A* means *arm*, that is, a performance of a limb at the upper end of the

body. The letter *L* means *leg*, that is, a performance of a limb at the lower end of the body. The letters *S* and *D* in the second position mean that, for the indicated correlation, the two musculatures correlated were on the *same* or *different ends* of the body. In the third position the letter *B* means that *both* lights and reaction board were seen by the subject. The letter *O* means that *only* the lights were seen by the subject, the reaction board being out of his line of vision. The letters *S* and *D* in the third position mean that, for the indicated correlation, *both* of the two musculatures correlated operated out of sight or within sight, or that *only one* of them operated out of sight the other being visible.

Analysis of the Data

The following observations may be made in analyzing the data presented in Table I.

1. The median reliability coefficient for the 6 performances is .96 ± .01.

2. Although the absolute differences in mean score are small for these 6 performances, the critical ratios are all significant (greater than 3) but one.

3. Inter-correlations of the 6 performances vary from .95 ± .01 to .72 ± .04, the median being at .82 ± .03.

4. The combination of the 3 factors represented by the symbols SSS, occurring 6 times in the table, has median correlation figure of .96 ± .01. These are the reliability coefficients.

5. The combination of the 3 factors, SSD, occurring twice has a median correlation figure of .93 ± .01. The difference between performances indicated here is one of visibility *vs.* non-visibility of the reaction board.

6. The combination DSS, occurring twice, has a median correlation figure of .92 ± .01. The difference indicated here is that of left limb *vs.* right limb.

7. The combination DSD, occurring twice, has a median correlation figure of .88 ± .02. Here the indicated differences include the one of left limb *vs.* right limb and visibility *vs.* non-visibility of the reaction board. In this case the

differential effects present separately in 5 and 6 (above) are present simultaneously.

8. The combination SDD, occurring twice, has a median correlation figure of .79 ± .03. The differences indicated here include the one of arm *vs.* leg and visibility *vs.* non-visibility of the reaction board.

9. The combination SDS, occurring three times, has a median correlation figure of .79 ± .03. The difference indicated here is one of arm *vs.* leg. The same situation with the added difference in the visibility set-up (8 above) produced the same correlation figure.

10. The combination DDD, occurring twice, has a median correlation figure of .78 ± .03. In this type of combination all 3 factors differ but the difference in the size of the median correlation from that noted for the combination SDS, in which only one of the three factors was variable across the correlated performances (9 above) is negligible.

11. The combination DDS, occurring twice, has a median correlation figure of .75 ± .03. In this combination the indicated differences include one of right limb *vs.* left limb and arm *vs.* leg. It differs from 10 (above) in that no difference in the visibility set-up is present between the correlated performances.

12. Thirteen combinations, each having S in the first position, have a median correlation of .87 ± .02 while 8 combinations, each having D in the first position, have a median correlation of .86 ± .02. This comparison indicates that, on the average, correlations between limbs on the same side of the body are but slightly higher than the correlations between limbs from opposite sides of the body.

13. Twelve combinations, each having S in the second position, have a median correlation of .92 ± .01 while 9 combinations, each having D in the second position, have a median correlation of .78 ± .03. This comparison indicates that, on the average, correlations between limbs at the same end of the body are higher than correlations of arm *vs.* leg.

14. Thirteen combinations, each having S in the third position, have a median correlation of .87 ± .02 while 8

combinations, each having D in the third position, have a median correlation of .87 ± .02. This comparison indicates that, on the average, correlations between performances under conditions such that the reaction board is visible or not visible in both tasks undergo no change in size when the conditions for one of the correlated performances are changed from visible to non-visible or vice versa.

Summary and Conclusions

Four motor tasks, known to be highly correlated, have been varied and repeated in such a way as to indicate the extent to which each of 3 factors entering into the performances contributes to the found high degree of correlation. These 3 factors are; first, the limb employed to do the task, whether arm or leg; second, the rightness or leftness of the limb used; and third, the visibility or non-visibility of the reaction keys. Six tasks in all were performed by each of 54 male subjects. Conclusions which may be made from a consideration of the data obtained from these 6 performances are itemized below.

1. Eight trials of 15 seconds each are sufficient in these 6 tasks to indicate that they are highly reliable, the median reliability coefficient being .96 ± .01.

2. The 6 tasks are about equally difficult, the smallest mean score being but 12 percent lower than the greatest.

3. The performances are highly stable, the critical ratios between the 6 mean scores being greater than 4 in all cases but 1.

4. Generality of ability, as indicated by correlation between performances, is somewhat greater on the average if in both of the performances correlated an arm or a leg is used (.92 ± .01) and lesser on the average if in one of the performances correlated an arm is used and in the other a leg (.78 ± .03.).

5. Generality of ability, as indicated by correlation between performances, is about the same on the average if in both of the performances correlated a right or a left limb is

used (.87 ± .02) or if in one performance a right limb is used and in the other a left (.86 ± .02).

6. Generality of ability, as indicated by correlation between performances, is apparently the same on the average if in both the performances correlated the reaction keys are visible or non-visible (.87 ± .02) or if in one performance the reaction keys are visible and in the other non-visible (.87 ± .02).

7. Generality of ability, as indicated by correlation between performances, is still present to a fairly high degree on the average when all 3 of the factors investigated vary simultaneously between correlated performances (.78 ± .03).

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THE RELIABILITY OF NONSENSE SYLLABLE SCORES DERIVED BY A GROUP METHOD OF EXPERIMENTATION

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Introduction

The purpose of this investigation is to compare the reliability of the scores of nonsense syllables having 80 percent associative value with the reliability of scores having 20 percent associative value,[1] and to determine the reliability of such scores when the experiments are conducted by a group method, rather than by the usual individual method.

The author, in collaboration with Lehman and McCue,[2] recently studied the effect of length of list of nonsense syllables upon the reliability of the scores. Seventy-six subjects (college students) learned six lists of syllables as follows: 6,6; 12,12; 18,18. Practice effect was controlled by the method of counter-balanced order and, the effect of differences in difficulty, by systematically shifting the syllables from one list to another as they were being arranged for the different subjects. The correlation coefficients between the paired lists, for time and trial scores, ranged from .61 to .87 (six coefficients altogether). With only one exception, the magnitude of the coefficients varied directly with the length of the list. The syllables used in that experiment may be characterized as difficult and fairly uniform in associative value—most of them being of 20 percent associative value or less, according to the Glaze list.

The aim of the present investigation is to study the relation of the reliability of nonsense syllable scores to the difficulty of

[1] By 80 and 20 percent associative value is meant those syllables so designated in the Glaze list. See Glaze, A. J., The association value of non-sense syllables, *Ped. Sem.*, 1928, 35, 255–269.

[2] Stroud, J. B., Lehman, A. F., and McCue, C., The reliability of nonsense-syllable scores, *J. Exper. Psychol.*, 1934, 17, 294–304.

the syllables, length being constant. For purposes of study, two lists of 15 syllables each were selected from Glaze's list of 20 percent associative value and two each from the list of 80 percent associative value.

Of major concern also in this investigation is the study of a group technique for conducting learning experiments. Without doubt, one of the pertinent criticisms of many, if not most, learning experiments is found in the relatively small number of cases employed. Many times, the number of cases has been too small to insure statistical reliability or to make adequate analysis of the results possible. One of the chief difficulties lying in the way of a group procedure has been that the subjects have had no way of knowing when they had satisfied the criterion of learning. In the present experiment an attempt has been made to develop a technique whereby each subject participating could determine accurately and quickly the correctness of each response as it is made. The advantages of a satisfactory procedure for conducting group experiments in learning are obvious—especially for exploratory purposes in the initial stages of a problem and for class demonstrations with elementary pupils. Professor Pressey pointed out, as early as 1921, the need for a method of conducting group experiments.[3]

Procedure

The students in four classes of elementary psychology, comprising about 180 altogether, were chosen as subjects. Absences from class on one or more of the experimental days and the inability of some of the subjects to master one or more of the lists decreased the number of subjects considerably—especially in the case of the difficult lists. The members of two additional classes were chosen for participation in the experiment involving the difficult lists. One-hundred-thirty-nine subjects completed the learning of the two lists of syllables having 80 percent associative value; and one-hundred-eighty-five subjects completed the two lists having 20 percent associative value.

Thus, the relative reliability of the syllables of the two degrees of associative value is to be determined by comparison of the correlation coefficients for the two paired lists. The product-moment method of computing the correlation was used. The experiments were conducted at the regular class periods each of which was fifty minutes in duration. Each list was comprised of fifteen syllables. The lists of subjects whose scores are utilized in the two correlation coefficients are not identical although the overlapping is more than 50 percent.

[3] Pressey, S. L., The influence of color upon mental and motor efficiency. *Amer. J. Psychol.*, 1928, **35**, 255–269.

In this experiment the speed of learning is measured by the method of recognition. The fifteen syllables comprising each list were arranged with sixty other syllables making a total of seventy-five syllables per list all of which had approximately the same associative value. The syllables were then arranged in fifteen rows making five to a row. Each row contained one of the fifteen syllables to be learned. Thus, altogether four such lists were prepared each of which contained seventy-five syllables arrayed in the manner just described. Care was taken to see that the fifteen syllables to be learned, hereafter designated as the *significant syllables*, did not fall into any easily recognizable pattern. Otherwise, their position in the rows was determined by random selection. The respective lists of syllables were mimeographed on heavy mimeograph paper.

After the lists were mimeographed, each of the fifteen significant syllables of each of the four lists was treated with a chemical (an idea suggested by the work of Professor John Peterson in connection with his self-scoring tests) to the end that when located and crossed out by the subject, the chemical reaction would be such as to reveal at once the correctness of the response. A standard solution of phenolphthalein was used for this purpose. A base (a standard solution of sodium hydroxide) was added to the black ink used by the subjects in making the checkings. The optimal ink-base solution was determined empirically. It was found to be about an equal amount of each. The presence of the base naturally tended to desaturate the ink, but it left it sufficiently distinct to indicate unmistakably when the subject crossed out the wrong syllable. The subject was instructed to cross out one and only one syllable in each row. It was possible for him to tell at once by the chemical reaction whether or not his response was correct. If correct, the area of the syllable immediately turned red; if wrong, it simply retained the color of the ink.

The chemical was applied to the mimeographed sheets on the appropriate syllables with a stylus of soft wood about one eighth of an inch in diameter, the point of which was rounded bluntly and symmetrically. Several methods of application were tried; but the method just mentioned appeared to be the most satisfactory. Brushes smeared the ink on the paper in such a way as to make the significant syllables detectable. Also, considerable care was required in choosing the best solution of phenolphthalein and the most suitable kind of paper. An alcohol solution, selected because of its fast-drying properties, was discarded because it tended to dissolve and blur the ink. A water solution proved to be equally unsatisfactory owing to the fact that the water tended to leave a blister on the paper. A solution of 45 percent water and 55 percent alcohol was found to be ideal inasmuch as no trace of any kind was left by which the significant syllables could be detected by inspection.

When the mimeographed pages had been treated in the manner described above, they were made up into packages containing 24 sheets, the maximum number of trials possible to give the subjects within a class period of fifty minutes. It was hoped that practically all of the subjects could learn the lists within this limit. This proved to be the case for the two lists of 80 percent associative value; but about 20 percent of the subjects failed to learn, to the point of one correct checking, one or both lists of 20 percent associative value.

The syllables were presented visually by the method of paired associates by means of specially constructed apparatus for exposing the cards to the class. The 15 significant syllables were printed on cards (one to a card) in letters two-and-a-half inches high; and paired with each such syllable was another syllable of approximately the same difficulty which was to serve as the stimulus. Thus, 15 pairs of syllables were presented to the subjects, one pair at a time, with an exposure period of approximately three seconds.

The rest of the procedure should be clear from the instructions read to the subjects, which are as follows:

"You are about to take part in a new psychological experiment. This is the first time that an experiment of this particular type has been conducted. Your full co-operation in making the experiment a success is earnestly solicited. You will be shown 15 pairs of nonsense syllables in rapid succession. Do not try to pronounce the syllables, but spell them out, as X–U–J. When all of the pairs have been presented, you will then be shown the first syllable of each pair and you will find and cross out the syllable that went with it in the original list, one of which will be found in each row. So that you may keep up with the experimenter, he will call the number of the rows as the cards are presented. Cross out only one syllable in each row. Be sure to cross out only one syllable in each row called. You may know when you have made a correct choice by the fact that the area of the syllable will immediately turn red. The list is regarded as learned when you have all of the 15 syllables showing the red reaction with no errors indicated." At the conclusion of the first presenting of the paired list the first syllable of the first pair was exposed and while exposed the experimenter said: "The syllable which was associated with this one is in the first row of the list you have before you. Find it quickly and make a cross in it." After a pause the experimenter continued: "You are to do the same thing in the other rows as the syllables are presented." (The syllables of the stimulus series were exposed for intervals of six seconds each.)

At the conclusion of the first trial the subjects were requested to place the sheet just finished under the bottom of the package. This was repeated at the conclusion of each trial. Presentation of the paired lists and of the recall (stimulus) series alternated until the experiment was finished, each student stopping when he had achieved 15 perfect responses during a single trial.

The 15 significant syllables of each list appeared in the mimeographed sheets in two different orders, including both vertical and horizontal arrangement, varying in regular alternation. Both orders varied from the order in which the paired lists were presented. Consequently, the syllables of the recall series, which always corresponded to the numerical order of significant syllables contained in the mimeographed sheets, had to be exhibited in two different orders.

In carrying out this experiment, the experimenter (the author) was assisted by two of his colleagues, Doctors W. H. Gray and J. W. Nagge. The subjects were especially instructed not to cheat. The assistants endeavored to detect cheating. The papers of any students suspected of cheating were discarded.

Results

The correlation coefficient between the scores of the two lists of syllables of 80 percent associative value, in the case of one-hundred-thirty-nine subjects who completed the learning of both lists, is $.64 \pm .03$. The correlation between the two lists of syllables of only 20 percent associative values, in the case of one-hundred-eighty-five subjects who completed both lists, is $.63 \pm .02$.

Taken at their face value, these results indicate that, for the length of list used in this study, there is no difference in

the reliability of the two paired lists. However, since about 20 percent of the subjects failed to learn one or both of the lists of 20 percent associative value, there is some justification for the conclusion that these syllables are more reliable than those of 80 percent associative value. Since those failing to satisfy the criterion of learning may be regarded as the poorest learners, this selective factor, naturally, would tend to limit the range—an influence which probably operated to lower the correlation between the two difficult lists.

The comparative difficulty of the lists of two degrees of associative value may be shown by the comparing of their respective mean scores. The average number of trials required to master the two lists of 80 percent associative value is 6.73; and that required to master the two lists of 20 percent associative value is 12.25. Only a negligible difference in trials required for mastery was found between the lists of comparable associative value. The effect of practice, with respect to the reliability of the lists and to their relative difficulty, was controlled by the method of counterbalanced order. A question of major concern in connection with this study is the general satisfactoriness of the technique for learning experiments. If sufficient reliability can be established, and if it can be demonstrated that the method does measure learning phenomena about as well as individual methods, the advantages of this or some other group technique must be apparent. Technically speaking, this method is feasible. Its administration is simple. Subjects have reported almost invariably that the procedure is attractive. Even when the chemical is applied by hand, as was done in this case, there is a tremendous saving of time. Furthermore, the work can be done by unskilled, student labor. Should the complete feasibility of this technique be established, it should be a fairly simple matter to have the forms printed and the paper treated chemically at the factory by some mechanical means.

The method lends itself to various experimental arrangements and the learning task may be made as simple or complex as is desired. It lends itself readily to the method of paired associates and the method of direct recall. It cannot, as now

used, be employed with the method of anticipation. It has the further limitation of being applicable only to the testing method known as recognition.

A comparison of the reliability coefficients obtained in the present study with those found where the customary individual procedure has been used indicates that from the standpoint of reliability, the group technique is about as satisfactory as the conventional procedure. Although statistical data are not at hand to substantiate the statement, it seems probable that the *means* of nonsense syllable scores in perhaps the majority of experiments where they have been used do not possess a high degree of reliability owing to the smallness of the number of cases employed. The group technique, if it proves to be satisfactory, affords a ready means of overcoming this limitation.

The reliability coefficients obtained in the present study may be compared with some of those obtained by individual methods. Stroud, Lehman, and McCue [4] obtained coefficients of .61 ± .05 between the trial scores of two six-syllable lists of nonsense syllables, of .73 ± .04 between the trial scores of two twelve-syllable lists, and of .77 ± .03 between two eighteen-syllable lists. They obtained coefficients of .68 ± .04, .87 ± .02, and .62 ± .05 between the time scores of the three respective paired lists. As is indicated in their article, the list of subjects upon whose scores these findings are based is characterized by a high degree of heterogeneity—the subjects ranging from college freshman to graduate students. Baxter [5] reports a correlation of .66 between the trial scores of two eight-syllable lists. Tomlinson [6] obtained a correlation of .57 ± .06 between the trial scores of an eight-and a twelve-syllable list of syllables, of .67 ± .06 between an eight- and a sixteen-syllable list, and, of .60 ± .06 between a twelve- and sixteen-syllable list. He obtained a correlation of .62 ± .06 between the time scores of an eight- and twelve-syllable list,

[4] *Op. cit.*

[5] Baxter, M. F., An experimental study of the differentiation of temperaments on a basis of rate and strength. *Amer. J. Psychol.*, 1927, **38**, 59–96.

[6] Tomlinson, C., *Studies in memory*, Master's Thesis, Kansas State Teachers College of Emporia.

of .58 ± .06 between the time scores of an eight- and a sixteen-syllable list, and, of .58 ± .06 between the time scores of a twelve- and sixteen-syllable list. Tomlinson's results are based upon 41 cases. A comparison of these results with those obtained in the investigation described in this study indicates that the latter parallel rather closely those obtained by individual procedures.

Further analysis of the data obtained in this study confirms the claims of similarity between the results derived by group and individual methods. The rate of learning, as indicated by learning curves, the effect of practice upon the form of the curves, and the dependence of the form of the curve upon the learning ability of the subjects as illustrated by these results parallel those obtained by individual procedure. A few sample cases will illustrate this point. Table I shows, for the

TABLE I

SHOWING THE EFFECT OF PRACTICE AND OF DIFFERENCES IN LEARNING ABILITY UPON THE FORM OF LEARNING CURVES

Trials:		No. Syllables Recalled per Trial													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Day	No. S's														
1	6	8.8	11.7	15.0											
2	5	10.8	12.0	15.0											
3	6	9.7	12.0	15.0											
4	10	10.7	11.9	15.0											
1	6	5.0	8.7	10.8	13.0	15.0									
2	9	7.6	10.4	12.0	13.4	15.0									
3	6	10.0	11.5	12.3	13.0	15.0									
4	9	9.7	11.2	12.3	12.1	15.0									
1	4	4.5	8.5	9.3	11.8	12.5	13.8	15.0							
2	7	6.7	9.4	11.3	11.7	12.4	12.9	15.0							
3	6	7.4	9.7	9.7	11.5	12.0	13.1	15.0							
4	6	9.5	10.0	11.7	11.7	13.3	13.0	15.0							
1–4	7	6.3	8.0	10.0	11.9	11.3	12.8	12.8	13.2	13.7	15.0				
1–4	4	4.2	7.5	7.0	10.2	10.5	10.7	11.8	11.5	12.5	12.2	13.1	13.8	13.0	15.0

syllables of 80 percent associative value, the rate of learning, the effect of practice, and the comparative rate for students of different levels of learning ability.

Learning curves plotted from the data given in the table

above would all show negative acceleration—a characteristic which is typical of material of this kind. Inspection of the data also shows that, in general, the steepness of the initial slope is directly proportional to the learning ability of the subjects. Practice has somewhat the same effect. Even for subjects making comparable scores, as in the case of the four groups who required five trials to master the lists, those whose performance fell in this group on the first day showed less initial progress than those whose second day performance placed them in this group. In general this tendency holds throughout. In short, practice makes for learning curves of greater negative acceleration even when its effect upon the number of trials required to learn is controlled. The results for the lists of 20 percent associative value are quite comparable in these respects to those just presented. While the number of overlapping cases is too small to make a generalization safe, (there is a difference of 5.5 trials in the average number of trials required to learn the easy and difficult lists), there is some indication that the easy lists show more negative acceleration than the difficult lists even when the number of trials required to learn the two lists is the same. This is especially significant since the subjects who require eight trials, for example, to learn a difficult list are considerably better learners than those who require an equal number of trials to learn an easy list. The data presented below bring out this relationship to some extent. The average number of syllables recalled on each of the first five trials of twenty-two subjects who required an average of 11.6 trials to master one or both of the easy lists is as follows: 6.0, 7.7, 8.8, 9.7, and 11.2. The average performance on the first five trials of thirty-five subjects who required an average of 12.1 trials to learn one or both of the difficult lists is as follows: 4.9, 6.2, 8.1, 8.6, and 9.2. The range of scores of the twenty-two subjects in the first comparison is from 8 to 14 and that for the thirty-five subjects in the second comparison is 10 to 17. These differences, especially in view of their consistency, indicate that learning curves based upon the scores of syllables of 20 percent associative value show less negative acceleration than do curves

based upon the scores of syllables having 80 percent asssociative value.

In so far as these results go, they suggest the following conditions which favor negatively accelerated learning curves, namely, superior learning ability, practice, and easy learning material. These observations are incidental to the main purpose of this study.

Summary

The correlation coefficients obtained in this study indicate that there is no difference between the reliability of nonsense syllables of 80 percent associative value and those of 20 percent associative value. The suggestion is offered, however, that the lists of 20 percent associative value might prove to be the more reliable under experimental conditions in which the subjects were given as many trials as required for mastery of all of the lists. These results indicate, further, that the group procedure employed is about as reliable and otherwise as satisfactory as the customary individual procedure. The time-saving value of the group procedure is obvious.

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A DIRECT READING CHRONOSCOPE WITH ACCESSORIES AND OPERATING PANEL

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The instrument described in this article was devised to meet the demand for a portable and flexible timing system for undergraduate and graduate work. Not only does this apparatus contain certain novel features but special attention has been directed as well to the design of an operating panel which would meet the needs of both the ordinary student and those interested in research. It is believed, therefore, that a detailed account of the construction and the manner of testing this timing system will be appreciated by investigators of reaction time situations.

Description of the Chronoscope *

The motive power for this instrument is a G.E. synchronous motor operating on 110–120 volt, alternating current, and rated at 1/100 H.P. and 1800 R.P.M. It is self-starting and self-synchronizing. A motor of this type keeps in step with the cyclic variations of the line voltage. In the case of 60 cycle current, the motor shaft would make thirty rotations per second. This motor is designed to keep in step with the changes in the voltage even when handling a 100 per cent overload. This fact in conjunction with the circumstance that the armature is relatively heavy would lead one to conclude that the speed of the shaft would vary little from uniformity as a result of slight changes in load. This conclusion was verified by direct measurements; it was found that changes resulting from the operation of the clutch mechanism were less than two milliseconds. Since the mass

* This apparatus was constructed in the New York University Machine Shop under the supervision of Walter Turnbull. Successful operation of this instrument is due in large part to the capacity of Mr. Turnbull and his staff to execute machine work of precision.

action of the clutch mechanism is approximately constant, it is possible to adjust the chronoscope to compensate for the small error involved.

The timing mechanism is a balanced system such as that first suggested by Dunlap (1). A horizontal cross section of this mechanism is shown in Fig. 1. The clutch magnets are

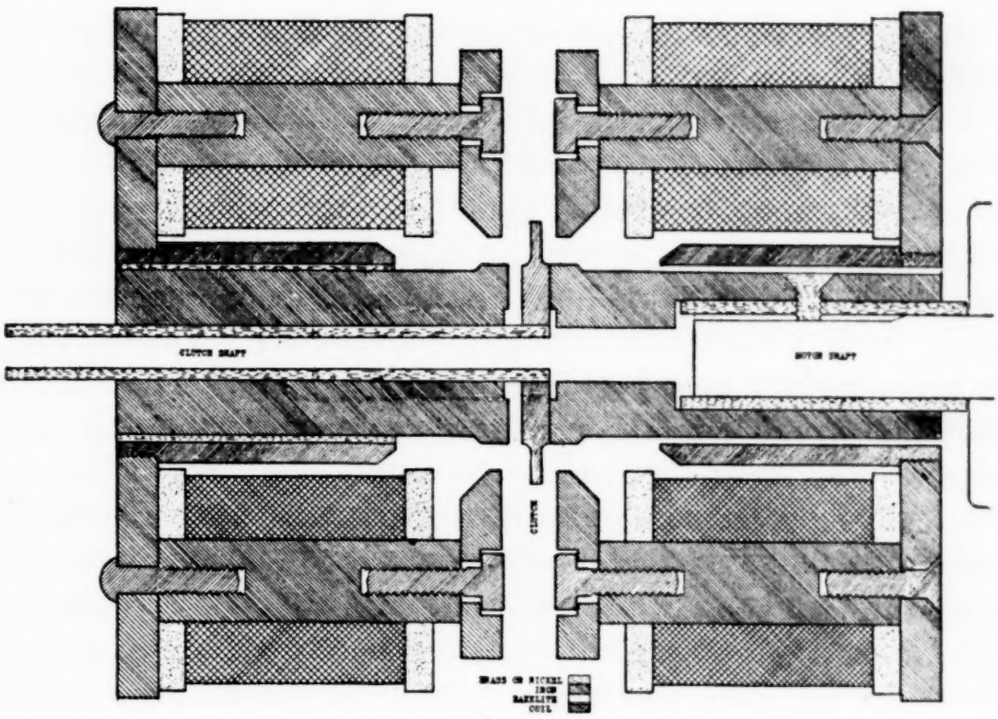

FIG. 1. Horizontal cross section of clutch and clutch magnets (not drawn to scale). Non-magnetic material (brass) was utilized at various places to produce a perfectly balanced magnetic system. When resting against a pole piece, the clutch disc is relatively much closer (.01″) to the magnet yoke than indicated in the above diagram.

wound to operate on 110–120 volt *direct* current. Each magnet has a resistance of 5000 ohms. The magnet (rear) nearest the motor has a pole attached to the motor shaft; hence, this magnetic pole rotates continuously while the motor is running. The other magnet (front) has a fixed magnetic pole. Between the rotating and fixed magnetic poles is an iron clutch disc. This disc is faced with sheet copper .004 inch thick. The copper facing not only improves the braking quality of the clutch but also provides a non-magnetic gap which facilitates the breakdown of the magnetic field when

the electric circuit is broken. To the disc is attached a non-magnetic tubular shaft which is coupled directly with a high speed counter. In our original model, the clutch disc was attached to a sleeve which moved to and fro independently of the shaft operating the counter. It was found, however, that this complication was unnecessary for satisfactory operation of the timing mechanism. Instead, the coupling was slotted to permit to and fro movement of clutch and shaft.

The counter was designed especially for high speed operation. It will record reaction times up to 100,000 units. On 60 cycle current, each unit equals one-three hundredth of a second. For those who wish to express their final statistical constants in terms of milliseconds, the result can be achieved easily by dividing by the conversion factor, 0.3. For instance, 30 units divided by 0.3 equals 100 milliseconds. The counter has the usual manual reset to zero. Resetting to zero requires no *visual* attention since the reset button automatically springs back to its resting position when the dial is reset to zero. This operation, therefore, can be consummated with the left hand while the time record is made with the right hand. The simplicity of this operation coupled with a *direct reading* dial, *i.e.*, the numbers on the dial are in the same form as in the record, enables one to measure reaction times both rapidly and accurately. After a short period of practice, an operator can record several hundred reaction times per hour. An automatic reset which could be operated electrically from a distance was considered. This device, however, was not incorporated since, as previously indicated, it would be an unnecessary complication for individual work.

Closing the Front Circuit after Presentation of the Stimulus. —A chronoscope operating electrically without the use of springs requires some device for automatically re-making one of the circuits after the stimulus is presented. In measuring reaction times, the clutch disc is normally at rest at the fixed (front) magnetic pole. When current is flowing through the front magnet, the clutch is held firmly against the fixed pole. If current is flowing only through the rear magnet,

the clutch is attracted and held by the rotating pole. If the front circuit is broken simultaneously with the presentation of a stimulus to the subject, the rear magnet attracts the clutch disc, thus setting the counter in motion. Before the subject releases the clutch disc by breaking the rear circuit, the front circuit must be made so that the disc will be attracted to the fixed pole, thus stopping the counter. A survey of the various procedures suggested for this purpose showed that they can be classified conveniently into two groups: (1) devices activated during the presentation of the stimulus and (2) closure of the front circuit through the response of the subject. Both procedures have their advantages. Dunlap (**2**) suggested the use of a relay for closing the circuit about 50 milliseconds after it is opened. The relay circuit is closed when the stimulus is presented. This procedure has the disadvantage of being indirect and of complicating the timing system with auxiliary circuits. A simplification has been suggested by Max (**5**), who closes the circuit directly through the stimulus key without the mediation of a relay. This operation involves breaking and subsequently closing the circuit as the key is depressed by the operator. The time elapsing between break and make depends upon the speed of depression of the key. It is evident that the operator must act quickly enough to close the circuit before the subject reacts, but must not close it before the rotating magnetic pole has had time to gain control over the clutch disc. Significant timing errors may be introduced by building up the magnetic field in the starting magnet before the rotating magnetic pole has gained complete control over the disc.

Closing of the front circuit through the reacting subject has been suggested by Heinlein (**3**). This writer used a reaction key with two contacts. When depressed, contact is made through the rear circuit. The stimulus key also is in the rear circuit and is closed to attract the disc to the rotating pole. The subject, upon releasing the reaction key, opens the rear circuit and closes the front circuit, thus attracting the disc toward the fixed pole. It is possible for a variable

error to creep in through the use of this arrangement because an interval of time elapses between the initial reaction of breaking the rear circuit and the subsequent closing of the front circuit. Since the keys activated by the operator and the subject are in the same circuit (rear magnet), Heinlein's system is necessarily a make-to-break procedure. It is worthy of note that a break-break operation also can be utilized, as indicated schematically in Fig. 2. Either this

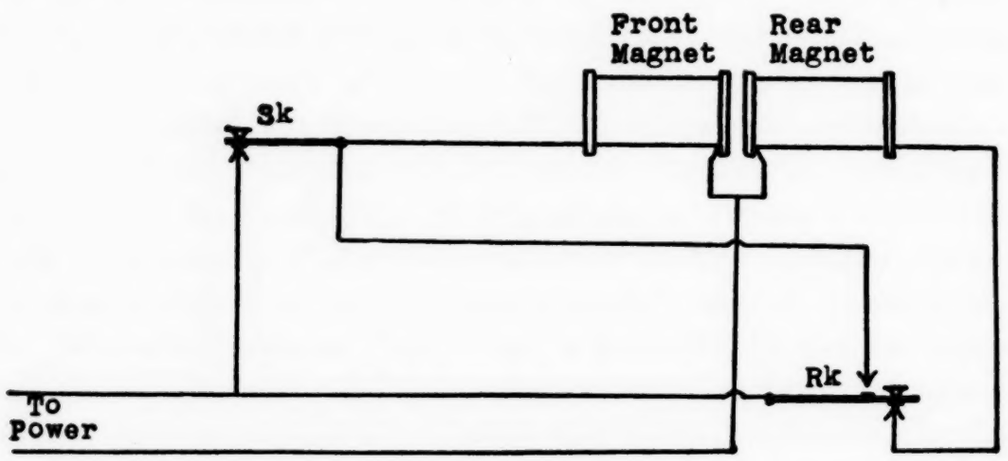

FIG. 2. Schematic diagram of wiring connections for closing the front magnet circuit by means of the response key. The front or starting circuit is first broken by operating the stimulus key, Sk, and later closed by the subject through release of the response key, Rk.

procedure or that suggested by Heinlein can be used with the chronoscope described in this article. Closing the front circuit, however, by means of the key or device which presents the stimulus is recommended since it eliminates the variable error just mentioned.

The standard procedure for closing the front circuit in the direct reading chronoscope is through the use of a high resistance relay. In our initial plan we designed a key which could be adjusted to close the circuit at any desired interval after presentation of the stimulus regardless of the rapidity of depression by the operator. The relay, however, is more general in its application since it can be utilized readily in connection with special devices, such as tachistoscopes, exposure pendulums, etc. Mechanical relays were also considered. The simplest of these consisted in closing the front

circuit by means of the movement of the clutch shaft toward the rotating pole. A device of this kind could easily be incorporated in the present chronoscope. A carefully constructed mechanical relay would undoubtedly give efficient service in the majority of reaction time situations. The electrical relay, on the other hand, would probably require less attention on the part of the operator, especially when unique reaction time set-ups are taken into consideration. The electrical relay finally incorporated in our chronoscope has a resistance of 12,000 ohms. Because of the extremely small current drain (10 milliamperes at 120 volts) of this relay, the time error produced by its action is negligible. The relation of the relay circuit to the clutch magnet circuits can be inferred from Fig. 3.

Sources of Power for Operating the Chronoscope

As indicated heretofore, this chronoscope is designed to draw its energy from the regular 110–120 volt alternating and direct current mains. Some laboratories, however, are provided with only one type of electric current. In many localities only alternating current is regularly supplied by the power companies. Some institutions have installed a converter to supply direct current to those laboratories requiring it. Others, as for instance, Columbia University, generate their own direct current for meeting light and power requirements.

Where direct lighting current is not available, the clutch coils could be replaced with coils wound for battery current. Since the regular clutch coils and relay draw very little current, a more practical solution of the problem would be the utilization of one of the relatively inexpensive conversion systems used in radio, as, for example, a generator, a power pack or a so-called B battery eliminator. Any one of these can be plugged into the regular 110–120 volt A.C. mains.

In localities where only direct current is available, the problem is not so simple. This is due in part to the fact that the current consumption of the motor is fairly large despite its small power rating. Synchronous motors consume

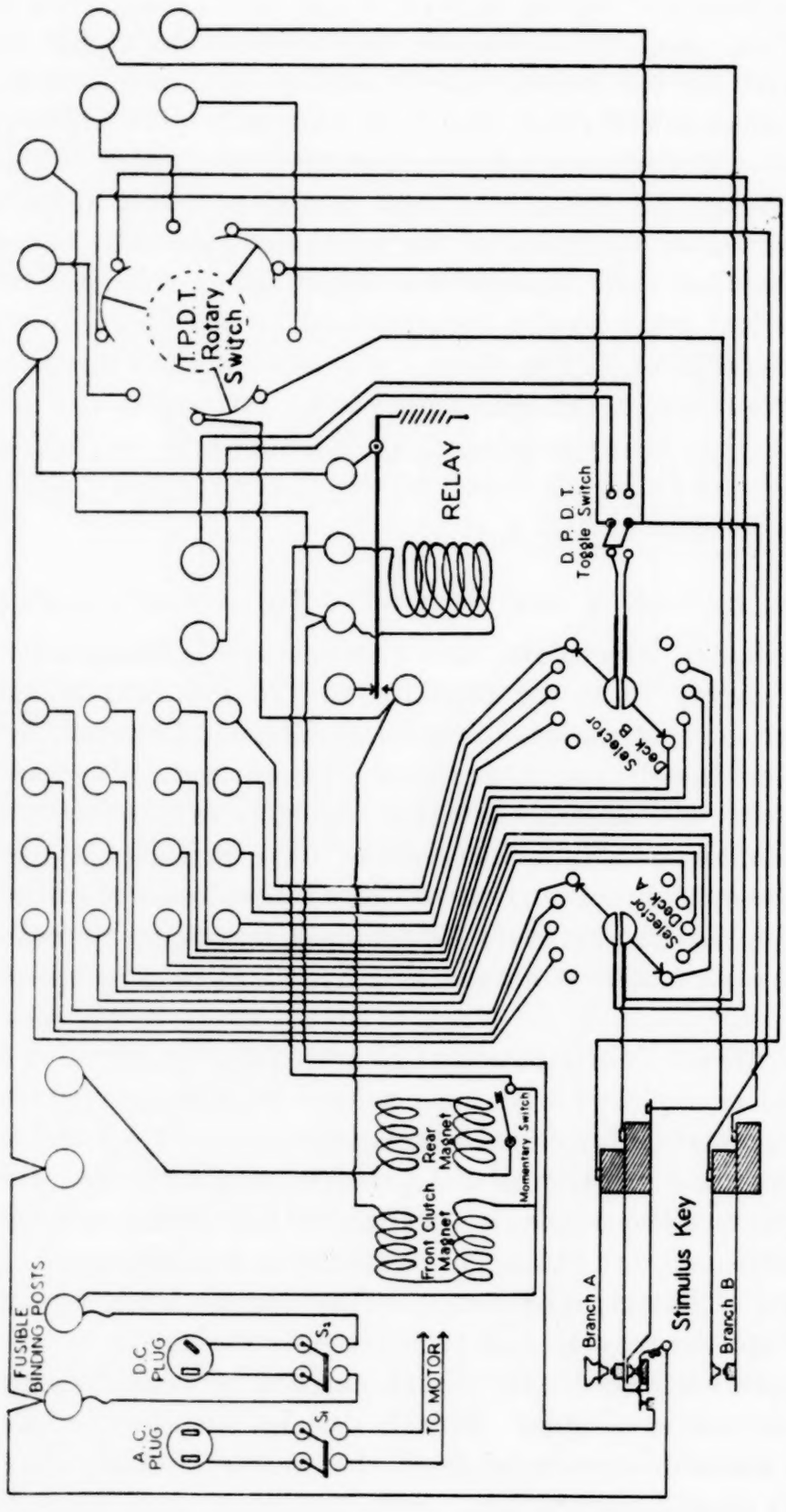

FIG. 3. Panel wiring diagram. Small open circles represent binding posts, the purpose of which is indicated in Fig. 4. For convenience in referring to Fig. 4 from the above drawing, the units of the panel, with the exception of clutch magnets and relay, are shown in the same relative position as in Fig. 4.

more energy than ordinary motors of the same rating because they must keep in step with the cyclic changes in voltage regardless of large variations in load. Tests made in our laboratory showed that this motor, operating on 120 V., A.C., draws about four amperes when starting and two amperes after reaching uniform speed, *i.e.*, after synchronization. The motor, however, will operate satisfactorily on less current and smaller voltages. It will start and synchronize readily on 30 to 40 volts. After reaching the steady state, it will handle the work of the chronoscope efficiently on 0.6 ampere or approximately 25 watts.

The use of a tuning fork as a means of operating this motor at a fixed speed will not succeed unless the electrical pulsations generated by the fork are converted into alternating current. This can be done with a single contact, electromagnetic fork by utilizing a low resistance transformer and suitable condensers. A more satisfactory method, however, is to provide the fork with a double pair of contacts on the inner and outer surfaces of the prongs. The two sets of contacts must be well insulated from each other. With this arrangement, a 60 cycle tuning fork furnishes 60 cycle current. This current is not sinusoidal but, if so desired, it can be made to approach the sinusoidal form through the use of capacity and inductance.

The Operating Panel

The chronoscope and several accessories are conveniently mounted on a panel. This panel is about 18 inches long, rests upon self-leveling supports and is provided with hand grips for carrying. It was intended to furnish a means for a wide variety of timing experiments without necessitating extensive wiring operations on the part of the experimenter. A vertical view of the essential parts of this panel is given in Fig. 4 and the wiring connections of the different items are indicated schematically in Fig. 3. The relay, not shown in Fig. 4, is situated just beneath the clutch system of the chronoscope. The various portions of the panel are clearly labeled so that the operator will experience little difficulty in setting up apparatus for reaction time investigations.

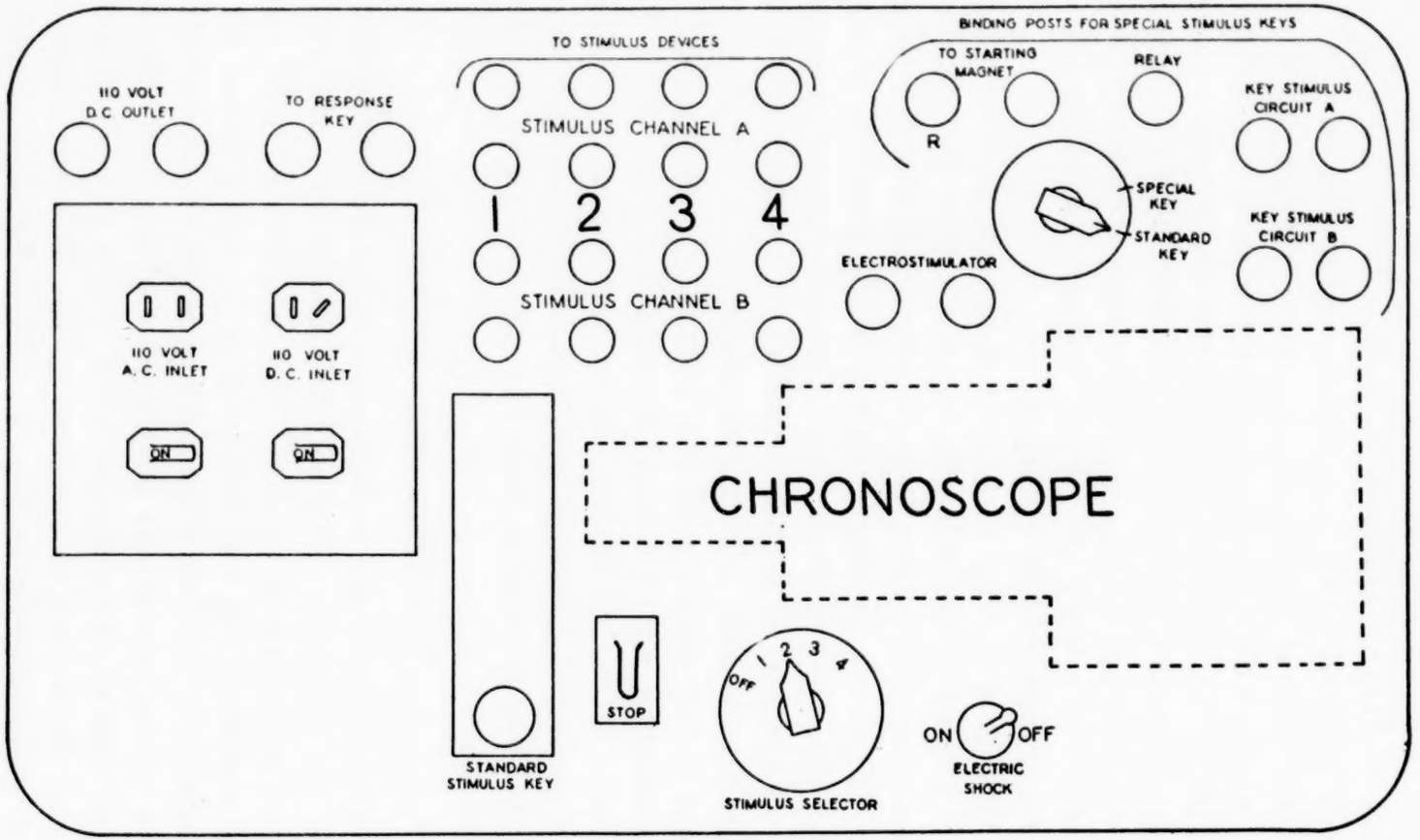

FIG. 4. Surface view of operating panel. The labels shown are the same as those engraved on the panel. The relay rests just beneath the clutch system of the chronoscope.

The A.C. and D.C. input receptacles are of different construction so that the respective connecting cords can be attached only in the correct manner. The D.C. outlet for accessory apparatus consists of insulated binding posts, each of which contains a fuse to protect not only accessories but also the relay and clutch system of the chronoscope.

The 'Standard Stimulus Key,' except the button, is concealed beneath the panel surface. This key is constructed to operate the relay and starting clutch magnet as well as to close *two* stimulus circuits. These two circuits are insulated from the clutch and relay circuits and from each other, thus permitting the use of special current sources for activating the stimulus mechanisms. The contacts (platinum-iridium) are backed with rubber to insure quiet operation, a type of construction first recommended by Newhall (**6**). For a sketch of this key, refer to Fig. 5. The electrical connections

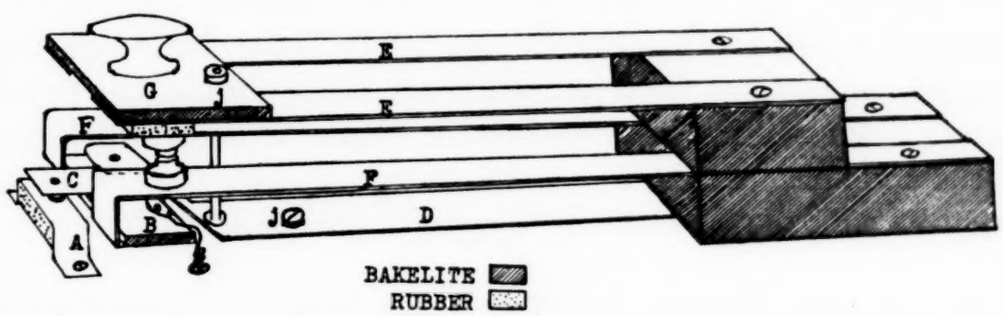

FIG. 5. Diagram of standard stimulus key in perspective. Stimulus circuit connections through *E*, *E*, *F*, *F*. *B*, Insulation between stimulus circuits and clutch circuit. *A*, *C*, Contacts for relay circuit. *j*, *j*, Adjusting screws for contact clearances. All leaf springs are phosphor bronze. All wiring connections made through bakelite base (not shown). For wiring details, see Fig. 3.

are indicated in Fig. 3. Just behind the chronoscope is a rotary switch (the 'key' switch) which should be set with the indicator pointing to 'Standard Key' when the standard key is in use. When devices other than the standard key are utilized for administering the stimuli, the switch indicator should be pointing toward the words 'Special Key.'

Sixteen binding posts, labeled 'To Stimulus Devices,' are provided for wiring to various stimulating mechanisms. These circuits in conjunction with the standard stimulus key furnish a convenient means for administering stimuli to the

subject in many different ways, either simultaneously or serially. These binding posts, numbered from left to right, are divided into two rows, namely 'Channel A' and 'Channel B,' corresponding to the two circuit connections of the 'Standard Stimulus Key.' If the 'Stimulus Selector' be set at '1,' then the first pair of binding posts of both stimulus channels are in circuit with the standard stimulus key. Suppose set '1' of channel A were connected to a sound producing apparatus and that of channel B were wired to an electric lamp. Depression of the standard key would then expose the subject simultaneously to auditory and visual stimulation. Posts 2, 3 and 4 could then be utilized for other stimulus categories. Special binding posts ('Electro-stimulator'), the connections of which have extra heavy insulation, are provided for high voltage stimulation. When the 'Electric Shock' switch is on, all connections to channel B are broken. In the case of ordinary voltages, the regular channel binding posts can be used. In many instances the wiring connections for stimulation are fairly simple, the panel labels being all that are necessary to insure a correct hook-up. Others, a few of which are mentioned in the next section, may be sufficiently unusual to require special attention.

Use of the Timing System with Special Accessories

Auditory Stimulation.—For comparing auditory discrimination with reactions to single stimuli, the simple neon oscillator represented in Fig. 6 is a convenient device for the use of students in experimental psychology. This oscillator is a midget in dimensions, all of the elements necessary for its operation being inclosed in a small metal case ($2 \times 3 \times 4$ inches). Its operation depends primarily upon the fact that the lamp will not pass electricity until the voltage has risen to a certain value (about 80–90 volts). Current from the 110 volt D.C. outlet leaks through the one megohm resistance to one of the condensers. When the electrical pressure in the condenser has risen to the critical value, it is discharged through the neon lamp and the head phones. The rate at which this process is repeated depends upon the magnitude

of the resistor and the condenser, the smaller the capacity the higher the musical note produced. To secure high or low notes during the progress of the reaction experiment it is necessary merely to set the stimulus selector, respectively, at '1' or '2' (see Fig. 4). When the 'Standard Stimulus Key' is depressed by the operator, the lamp and condenser circuits are closed simultaneously, the former through channel B, the

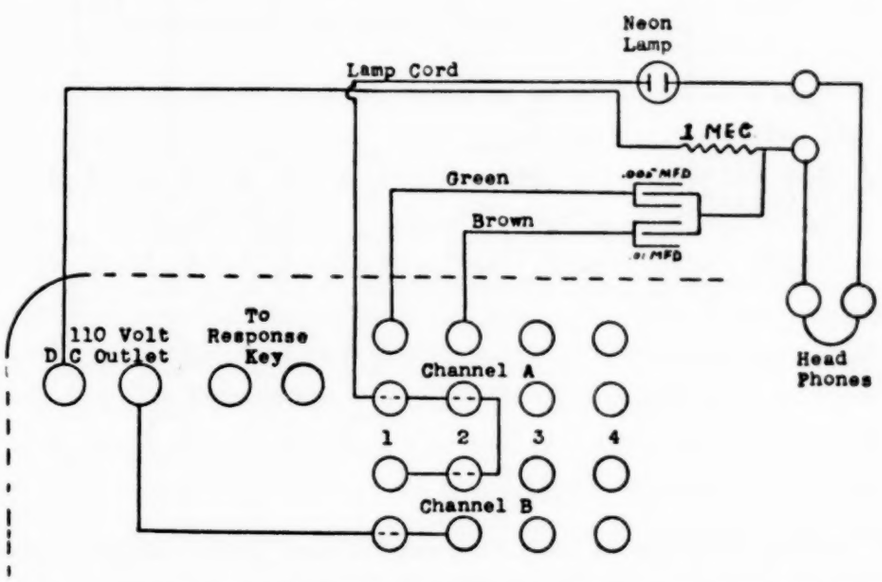

FIG. 6. Wiring diagram of midget oscillator and one type of connection to operating panel.

latter through channel A. If the lamp were glowing continuously, channel A only would have been utilized but the simultaneous closing of two circuits affords the more reliable operation. The glow lamp used was a one watt G.E. type S-1. The oscillator produces the steadier musical notes when the direction of the current is such that the wire coil, not the central core, glows. When the central core glows, the polarity can be readily changed by reversing the position of the D.C. wall plug.

Visual Stimulation.—It has been shown recently that neon glow lamps, because of negligible time lag in lighting, are preferable to incandescent lamps for reaction time investigations (**5**). The writer and others, before the introduction of the commercial glow lamp, had been partially successful in meeting the objection to the incandescent lamp through the

use of the Geissler tube. Two or more glow lamps filled with different gases can be utilized in measuring the capacity to discriminate between two or more photic stimuli. Figure 7,

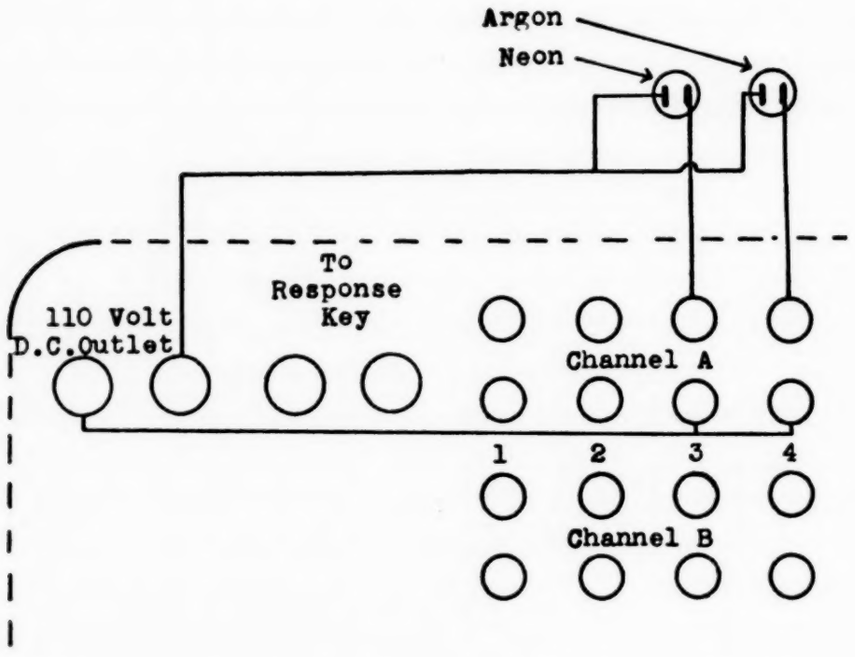

FIG. 7. Wiring connections to operating panel of glow lamps utilized for reactions involving photic discrimination.

for instance, shows the necessary wiring for using G.E. type S-2 neon and argon lamps as sources of yellow and violet light. Current from the 110 volt D.C. outlet passes through the lamps via the third and fourth pairs of binding posts. If reactions involving discrimination to light and sound be desired, the first and second posts can be connected to the oscillator, as previously described. As noted heretofore, the nature of the stimuli administered to the subject will depend upon the position of the indicator on the dial of the stimulus selector.

In the case of special exposure devices, such as shutters and pendulums, there is ordinarily an appreciable lapse of time between the act which initiates the operation of the device and the presentation of the stimulus. In such instances, the investigator must resort to the connecting system, designated 'Binding Posts for Special Stimulus Keys' (see

Fig. 4). The practical use of these will be discussed at some length in the ensuing discussion of special stimulus keys.

Special Stimulus Keys.—Any device other than the standard stimulus key which sets the counter of the chronoscope in motion is herein referred to as a special stimulus key. The bank of auxiliary binding posts just mentioned furnishes a convenient means of making the necessary electrical connections with mechanisms of this type. Under such circumstances, the indicator of the 'key' switch should be pointing toward the words, 'Special Key.'

(1) *Vocal Stimulation.*—Voice keys, such as the Dunlap, which, when acted upon, produce no prolonged break in the electrical circuit, do not require the use of a relay. One voice key is coupled to the binding posts labeled, 'To Starting Magnet,' the other, to those designated 'To Response Key.' The set-up is then ready for a variety of reaction time investigations involving a vocal response to a vocal stimulus. The response may be made through any type of voice key, as, for instance, the lip key. If the latter, however, is used by the operator, it must be provided with a contact for closing the relay circuit. One contact point of the relay is connected to post 'R,' the other is coupled to the 'Relay' binding post (Fig. 4). In fact, this form of connection should *always* be utilized for relay operation.

(2) *Special Exposure Mechanisms.*—Verbal material in written or printed form is usually presented by means of a special device, such as, a tachistoscope, a shutter, or a pendulum. Each involves the use of the relay in the manner just described. The exposure apparatus, therefore, must possess two types of contacts, a break contact for opening the circuit through the starting magnets and a closing contact for the relay circuit. The mode of operation of the contact mechanism will depend, of course, upon the type of exposure apparatus utilized. In the Harvard tachistoscope, for instance, the front clutch circuit can be broken by permitting the dropping shutter to depress a leaf spring at the end of its fall.

The same principles of operation apply to mechanisms for presenting other forms of stimulation, such as the produc-

tion of sound through the use of an acoumeter or a sound hammer. It is worthy of note that many of the exposure mechanisms just mentioned have been utilized for presenting other than visual stimuli. The pendulum, for instance, furnishes a convenient means of handling many types of stimulation, especially electrical, visual and auditory (4).

It should be pointed out, on the other hand, that exposure mechanisms involving *sudden* illumination of visual material can be operated without the use of a special key. The standard key is sufficient for such situations. In this case, the illuminating elements are wired directly to the regular stimulus binding posts. This procedure, of course, applies to any exposure apparatus in which there is a negligible lapse of time between the act initiating the operation of the device and the actual presentation of the stimulus.

On the extreme right of the panel (see Fig. 4) are two pairs of binding posts labeled 'Key Stimulus Circuit A' and 'Key Stimulus Circuit B.' These correspond, respectively, to channels A and B of the regular stimulus circuits. They enable the experimenter, while utilizing a *special stimulus key*, to avail himself of the convenience of the regular stimulus binding posts and the stimulus selector. For wiring details, inspect the diagram shown in Fig. 3. Suppose, for instance, an auditory stimulus be presented simultaneously with the visual material. If the auditory mechanism be wired to a pair of binding posts in channel A, then the posts labeled 'Key Stimulus Circuit A' must be connected to a *make* contact operated by the tachistoscopic device. If both stimulus channels be used, as in the oscillator set-up previously described, then double contacts must be provided for the tachistoscope, utilizing both key stimulus circuits, A and B. If an electrical disturbance be applied to the subject, the electrical device is connected to the 'Electrostimulator' binding posts, the shock switch is shifted to the 'On' position and the electrostimulator is closed by the tachistoscope through key stimulus circuit B. These examples will serve to give the reader a partial conception of the methods available for utilizing key stimulus circuits, A and B.

Validity and Reliability of the Chronoscope

What Kind of Accuracy should a Chronoscope Exhibit?—This depends upon the nature of the tasks it must perform. In the measurement of reaction time we are obviously dealing with a highly variable function, one in which the measurement of variability is fully as important as the measurement of central tendency. The significance of precision of measurement for a variable function is quite different from that for a condition exhibiting little or no variability. Validity and consistency are the most important criteria in the measurement of a variable, whereas great precision is one of the most desirable achievements in the measurement of a constant.

To state the matter more concretely, suppose our chronoscope measured time in microseconds (one-millionth of a second). Such a small unit might be of some importance in the measurement of a highly constant condition, as, for example, the speed of light in a vacuum. It is quite obvious, however, that such a small unit is unnecessary for satisfactory measurement of the variable trait, known as reaction time, be it for humans, infra-human animals or plants. Several investigators, including the writer (**4**), in treating reaction time data recorded in milliseconds, have arranged their data in the form of frequency distributions involving class intervals several times as large as the unit of measurement. Given a chronoscope which delivers accurate measures, this procedure is not only practical but also conducive to a more adequate interpretation of results. It is an admission, however, that *validity* rather than precision is the more important consideration in the measurement of a variable condition such as reaction time. Our interest in the variability of the trait also makes *consistency* a highly significant criterion of measurement. The ideal, of course, would be an instrument which never varies in its behavior.

There is a practical advantage in using an instrument which measures in units approximately the size of the class intervals one would ordinarily choose in treating reaction time data. By recording to the nearest unit, it eliminates the labor of grouping the data into class intervals. A five

millisecond unit is probably sufficiently large for all reaction time work. The unit in the present chronoscope is about three milliseconds.

The Source of Power as a Control of Motor Speed.—The widespread use of electric clocks has directed the attention of the large power companies to the need for delivering current with a precise number of voltage variations per second. Many of these organizations succeeded so well in this effort that a good electric clock operating on alternating current would not vary from correct time by more than a few seconds in the course of a year. The recent tendency to install automatic devices for keeping the voltage variations in step with an accurate clock should be conducive to even greater precision in the future. Under present conditions, the A.C. output of the large power companies furnishes a convenient and accurate means of regulating the speed of timing devices.

Adjustment of the Chronoscope.—Given a motor running at the correct speed, errors in timing must arise from maladjustments of the relay and clutch system. Dunlap (1) and later, Poffenberger and Morgan (7), stated the essential conditions for reliable operation of the balanced magnet type of chronoscope. These are as follows: (1) front and rear magnets with cores and other iron bearing parts of the same form, thus insuring the same behavior on the part of the magnetic circuits of the two magnets; (2) windings of the same resistance and the same number of turns; (3) proper adjustment of the pole pieces; and (4) action of the current upon the magnets for about the same length of time or design of the instrument so that this difference in time has no great effect. We might add a fifth condition, namely, adjustment of the relay.

The first two conditions were met during the construction of the magnets. That these conditions were met in the six chronoscopes constructed was indicated by the fact that, after final adjustment, the time records did not change when the electrical pressure on the clutch coils was varied from 70 to 120 volts. Passage of the current, moreover, through both circuits for ten minutes produced no apparent disturbance of the balance between the two electromagnets.

The fourth condition was met in part by constructing magnets with large time constants and in part by facing the clutch disc with copper. This latter operation provides a non-magnetic gap in the magnetic circuit which facilitates a rapid breakdown of the magnetic field at the time the electric circuit is broken.

The third condition is met by to and fro adjustment of the pole pieces, thus varying the air gap between disc and magnet yoke when the former is resting against either pole. The air gaps for the two yokes were first made as nearly equal as possible through the use of measuring gauges. Little further adjustment was necessary under test conditions.

Another important consideration was the adjustment of the relay. Improper regulation of this mechanism produces not only a constant error but also greater variability on the part of the chronoscope. Being an extremely rapid relay, the chief adjustment was a retardation of its speed. The relay was finally adjusted to close the front circuit about 30 milliseconds after it was opened. This permitted ample time for the rotating magnetic pole to gain complete control over the clutch disc.

Final tests of validity and reliability were made with a gravity chronometer. Thirty readings were taken from each chronoscope for a 60 unit interval (200 milliseconds). As stated heretofore, each unit equals 1/300th of a second. The results of these tests are summarized in the following table:

Chronoscope	Mean	Mean Deviation
No. 1	60.13	0.11
No. 2	59.92	0.24
No. 3	59.86	0.18
No. 4	60.07	0.08
No. 5	59.78	0.14
No. 6	59.97	0.09

Tests of two of these instruments, using a 30 unit interval (100 ms), furnished results comparable with those for the 60 unit interval. In the case of a 15 unit interval (50 ms), the variability, on the other hand, was larger than that for the 30 and 60 unit intervals, thus indicating an approach to the lower limit of serviceability of the instrument.

The Gravity Chronometer

In reporting the results of the foregoing tests, no mention was made of validity or consistency of our criterion, the test instrument. As a test apparatus, it should exhibit very little variability and a very small constant error. Gravity is an ideal regulative factor for testing timing systems because the gravitational force at a given point on the earth's surface is extremely constant. For this reason, the most accurate clocks, as, for example, the master clocks at the Naval Observatory, still utilize gravitational force as a speed control. Well known examples of test apparatus of this type for chronoscopes are the Cattell gravity chronometer and the Wundt control hammer.

Assuming the constancy of the gravitational pull of the earth, the accuracy of our test apparatus depends finally upon details of mechanical construction. In the present chronometer, a weight released from a split-core magnet operates circuit breakers during the course of its fall. A split-core magnet was utilized for this purpose about 30 years ago by Wolfe and later by Klopsteg. These and other workers, however, failed to give sufficient attention to some of the conditions most essential in determining the grade of accuracy of mechanisms of this type. These conditions are:

1. Influence of residual magnetism and rapidity of breakdown of the magnetic field.
2. The retarding effect of air resistance.
3. For short time intervals, errors of considerable magnitude may be introduced as a result of the slow movement of the weight during the early part of its fall. A weight, for instance, at sea level, drops only 12 mm in the first 50 milliseconds.
4. Errors resulting from the operation of devices for opening or closing chronoscope circuits.

Condition No. 1.—Under certain circumstances, the first condition may be quite significant. Errors of this kind are favored by the practice of using a hardened steel ball as a weight. The steel ball in contact with the iron core of the magnet would tend to resist the disappearance of the magnetic

field after the electric circuit is opened. Four methods are available for minimizing the influence of this factor:

(*a*) The employment of as large a weight as can be handled conveniently.

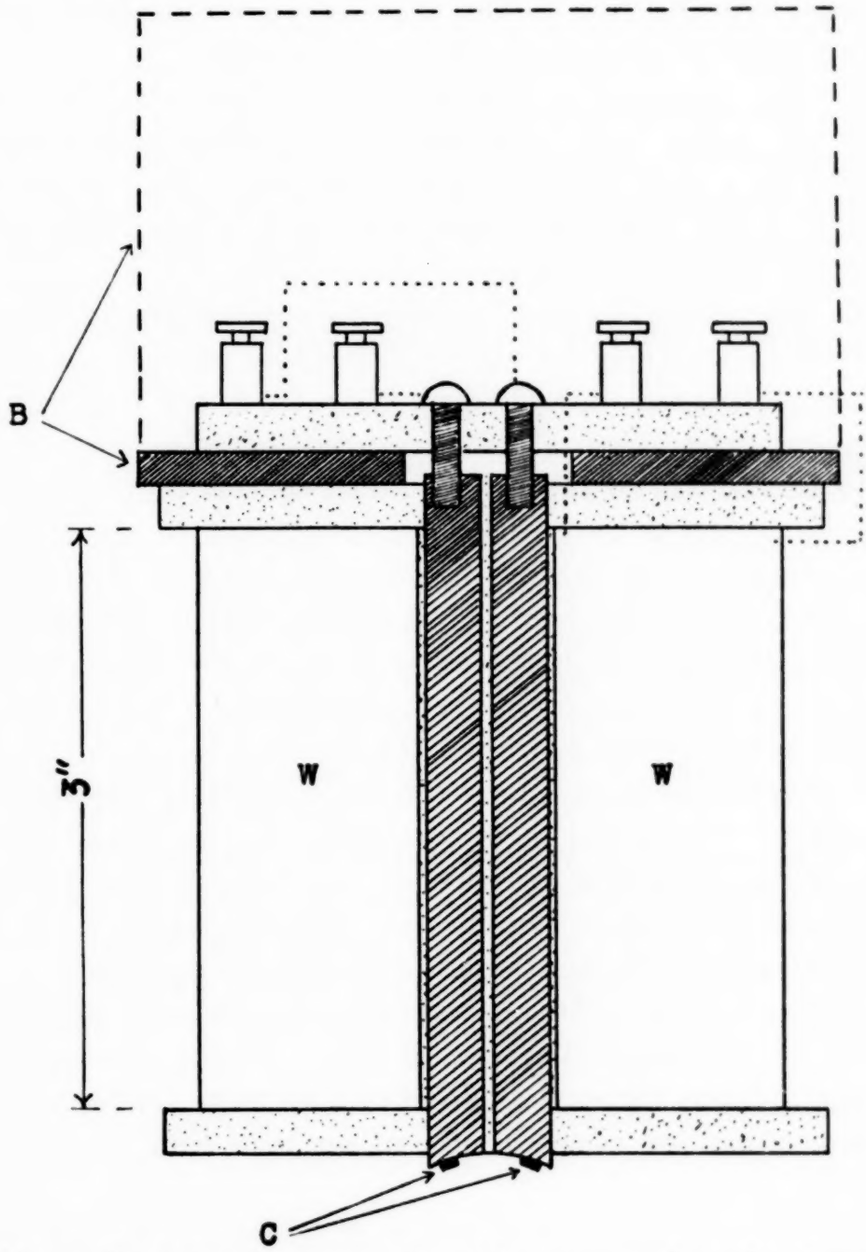

FIG. 8. Vertical cross section of retaining magnet of gravity chronometer. Section-lined portions are iron; dotted areas, bakelite; dotted lines, wiring connections. *W*, Winding of No. 28, cotton-enamel covered magnet wire. *C*, Silver contacts. *B*, Iron bracket for attachment to vertical support.

(*b*) Disintegration of the field can be facilitated by providing a non-magnetic gap between the weight and the

magnet core. This was done in the present instance by placing silver contacts on the concave surface of the core. For details, see Fig. 8. These not only provide an air gap but also insure good electrical contact between the weight and the two core halves. They also serve to prevent lateral displacement of the weight during its release.

(*c*) The influence of the magnetic factor was also minimized by using soft iron and by utilizing non-magnetic material as a part of the weight structure. This latter consisted of a soft iron shell filled with lead, a procedure which supplies a heavy piece of small dimensions.

(*d*) The errors induced by residual magnetism, etc. can be eliminated effectively by the utilization of two sets of circuit breakers. Instead of reckoning time from the beginning of movement, the interval is measured between two points during the course of fall. The merit of this method will be better understood by turning our attention to an example. Let us suppose the weight is retained for two milliseconds after the circuit is broken. This means that it will take two milliseconds longer than otherwise to reach the circuit breaker which stops the counter of the chronoscope. This error, as can be readily inferred, would not be introduced in the case of an interval measured between two points in the weight's trajectory. The speed of fall, in other words, would always be the same regardless of whether the weight were retained for two milliseconds or two hours. Other advantages of this arrangement will be mentioned in another connection.

Condition No. 2.—Air resistance is not especially important because of the short distance of fall. In our chronometer, the weight drops through a gap of two meters. Air resistance was minimized by construction of an iron shell having the form of a torpedo.

Condition No. 3.—Small errors of observation inevitably occur in determining the distance of fall from retaining magnet to circuit breaker. The time error produced thereby is proportional to I/gt. This error, therefore, is greatest for short intervals. For a divergence of one millimeter in reading the scale, the following time errors would result in the case of different distances of fall:

Time Interval	Distance of Fall (New York)	Time Error I/gt
50 ms	4.90 cm	2.04 ms
200 ms	19.60 cm	0.51 ms
400 ms	78.42 cm	0.25 ms
600 ms	176.45 cm	0.17 ms

These figures furnish an argument for checking chronoscopes against long time intervals. Yet it is not wise to assume that the chronoscope would perform equally well on short intervals. The observational error, however, would have little significance for short intervals measured between two points in the course of the fall. If time is reckoned after the weight has dropped 148.6 cm, 50 ms would elapse in falling 176.4 cm. In this case, a reading error of 1 mm would introduce a time error not greater than 0.2 ms.

Condition No. 4.—In testing a balanced magnet chronoscope, provision must be made for closing the relay circuit at the time the torpedo is released. This can be affected either through the use of a special key or by closing the circuit by means of the falling weight. This latter operation, however, might appreciably retard the movement of the torpedo. This also holds true for circuit breakers in the course of fall. Errors of this sort can be minimized in part by utilizing an unusually heavy weight and in part by installing easily operated circuit breakers.

The chronometer, as finally constructed, possesses a split-core magnet wound to operate on 110–120 volt current. A vertical section of this coil is shown in Fig. 8. This diagram is drawn to scale so that the coil can be duplicated readily by those interested. The torpedo weighs about four pounds and operates contacts mounted on movable carriages. The weight, after falling two meters, is caught quietly in a leaf spring pocket. The contact carriages possess runners which slide in lateral grooves in a vertical beam of hard wood. The contact breaker consists of a small metal reed counterbalanced to keep it in a horizontal position of contact. These breakers have been supplied recently with contacts of special design which maintain good electrical connections under all operating conditions. Operation of the circuit breaker simultaneously closes another circuit. This latter is convenient

for operating the relay and for checking chronoscopes other than the balanced magnet type.

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DISCUSSION

THE CONDITIONING OF VOLUNTARY REACTIONS

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In the April '36 issue of this *Journal*, C. N. Rexroad states (p. 144): "The second assumption . . . that voluntary as well as reflexive acts are capable of being conditioned . . . is, as far as the author is aware, without experimental support," and he proceeds to outline a 'first attempt' of a conditioning experiment in which the subject "would react to the primary stimulus from 'instructional necessity' rather than 'reflexive necessity'." In a subsequent issue (June, '36, p. 398), J. J. Gibson, discussing an experiment by J. M. Stephens, writes: "If responses of the reaction experiment are subject to conditioning of the type found in the reflex experiments, much of the speculative use of conditioning to explain the formation of complex habits is given an added plausibility," while Stephens in reply says: "Mr. Gibson is right in pointing out that to demonstrate conditioned voluntary reactions one should employ some such control as he suggests. I shall hasten to provide such control so that my data will have more bearing on that particular problem" (p. 399).

In view of these statements by Drs.: Rexroad, Gibson, and Stephens, may I call attention to the fact that: (1) Experiments on the conditionings of such voluntary reactions have been conducted in the Russian laboratories for the last twenty years and their results presented (in English, French, and German) by Bekhterev and others. (See, for instance, BEKHTEREV, V. M., *General Principles of Human Reflexology*, pp.: 309–310; 358.) (2) Four such extensive experiments, in which no less than 400 human subjects had been used, were reviewed and statistically treated by the writer (*Arch. Psychol.*, 1933, *No. 148*, paragraphs 75, 87–89) from which the following quotations are perhaps particularly germane: "Osipova also reports that 51 blind children, 9–18 years of age, only four of whom could establish, in 40 trials, a C–R to shock with an electric bell of 826 d.v. as the conditioned stimulus, readily formed the C–R in 4–18 trials when the command 'raise your finger' was substituted

for the shock" and the conclusion (p. 104): "C–Rs with words [instructions] as the conditioning stimuli (incidental association) do not as a rule become experimentally unconditioned." (3) More than a score of such experiments have in recent years been abstracted in the *Psychological Abstracts*. (4) Rexroad's specific conditioning technique of the subjects 'turning a handle' so that the response to be conditioned 'may be exhibited in varying amounts' was previously used in a number of experiments (*Arch. Psychol., ib.*, p. 73, line 4: "The reaction which the children had to perform upon the experimenter's signal was the moving of their forearms along an arc in a special apparatus permitting the ready recording of the extent and character of the movements)." (5) In at least one American experiment (COHEN, L. H., HILGARD, E. R. and WENDT, G. R., Sensitivity to light in a case of hysterical blindness study by reinforcement-inhibition and conditioning methods, *Yale J. Biol. Med.*, 1933, **6**, p. 65) the response conditioned was clearly of a voluntary or free reaction type, while in another, in which the primary stimulus of an electric shock failed to evoke the desired withdrawal response, the conditioning was successfully executed by "instructing the subject to withdraw her hand voluntarily each time she felt the shock" (SEARS, R. R., and COHEN, L. H., Hysterical anæsthesia, analgesia, and astereogonosis, *Arch. Neurol. and Psychiat.*, 1933, **29**, p. 269).

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